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Faculty of Electrical Engineering

Diploma Thesis

BuildingLAB: Predictive control of buildings

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ZADÁNÍ DIPLOMOVÉ PRÁCE

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Název tématu: **BuildingLab: prediktivní řízení budov**

Pokyny pro vypracování:

1. Seznamte se s přístupy k integraci prediktivního regulátoru (MPC) do stávajících systémů řízení topení, ventilace a klimatizace (HVAC).
2. Navrhněte a implementujte vhodnou topologii výpočetního systému pro MPC, který bude umožňovat komunikaci s HVAC systémem i s uživatelským rozhraním pro ladění MPC regulátorů.
3. Uživatelské rozhraní navrhněte a implementujte tak, aby umožňovalo simulaci chodu libovolné budovy z předdefinované sady budov pro různé nastavení prediktivního regulátoru, různé klimatické podmínky a proměnné požadavky řízení. Dále toto rozhraní bude umožňovat posuzovat kvalitu řízení na základě míry porušení požadavků řízení a spotřeby energie.
4. Integrujte celý systém a ověřte správnou funkci na pilotním projektu prediktivního řízení budovy ČVUT v pražských Dejvicích.

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Declaration

I declare that this diploma thesis was created entirely and only by me and that I used only materials cited in an attached list.

Prague, 10.5.2012

Pavel Tomášek

signature

Prohlášení

Prohlašuji, že jsem svou diplomovou práci vypracoval samostatně a použil jsem pouze podklady (literaturu, projekty, SW atd.) uvedené v přiloženém seznamu.

V Praze dne 10.5.2012

Pavel Šomášek

podpis

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Abstract

Control engineering is quite an elusive discipline particularly when explained to people, who have another profession. It is often difficult task to explain how the controller works, to create an insight into its action and to define the whole field of its responsibility.

HVAC (Heating, Ventilation and Air Conditioning) engineers often have requirements like the one that they want their ventilators to work from this time to that time. When they are asked why, the answer often is that it is a tested setting which works, saves energy, etc. In this case, it should be instead the responsibility of the controller to decide when the fans are powered on and when they are not. Sometimes it is hard to accept and absorb the control theory philosophy.

The problem of understanding the feedback control starts to be even bigger, when advanced technologies are applied. One of these technologies starts to be MPC (Model Predictive Control) especially in the last few years. In order to make not only the people working in HVAC branch but also managers understand the whole process of control, it is needed to some way expound them the MPC strategy. Unless they check the idea themselves, they will not be willing to implement the strategy in practice even though the advanced MPC was proven to be capable of saving up to 30% of the total heating bill.

Hence the goal of the work is to develop a tool, that will bring the MPC strategy closer to people; the web application called BuildingLAB.

This text deals with design of such a tool, which allows the user to simulate the MPC control strategy. Mathematical models of the CTU-FEE building in Prague – Dejvice will be used as the demonstration of the application operability.

The application is described from the view of the user in the form of a user manual and then its development from the software designer point of view is captured.

Abstrakt

Řízení je poměrně těžko postižitelná disciplína, zvláště pokud je vysvětlována lidem, kteří pracují v jiném oboru. Je často těžkým úkolem vysvětlit, jak pracuje regulátor, předat vhled o tom, proč zasahuje daným způsobem a definovat celou oblast jeho odpovědnosti.

Inženýři, pracující v oblasti HVAC (Heating, Ventilation and Air Conditioning) často chtějí, aby se např. ventilátory točily v nějaký specifický, jimi definovaný časový interval. Když jsou tázáni proč, tak odpoví, že je to ověřené nastavení, které funguje, šetří energii apod. V tomto případě by to ale měl být právě regulátor, který rozhodne, kdy jsou ventilátory zapnuté a kdy vypnuté. Někdy je prostě těžké pochopit a vstřebat filozofii teorie řízení.

Problém s porozuměním zpětnovazebnímu řízení se ještě prohlubuje, když jsou použity pokročilé technologie. Jednou takovou technologií je zvláště v posledních letech MPC (Model Predictive Control). Aby lidé, pracující v oboru HVAC, ale i manažeři porozuměli celému procesu MPC řízení, je třeba jim nějakou cestou přiblížit jeho metodiku. Pokud si totiž sami tuto myšlenku neověří, nebudou ochotni nasazovat tento způsob regulace v praxi, přestože bylo prokázáno, že dokáže uspořit až 30% nákladů na topení.

Proto je cílem této práce vyvinout nástroj, který lidem přiblíží strategii MPC; webovou aplikaci BuildingLAB.

Tento text se zabývá designem takového nástroje, který umožňuje uživateli simulovat běh MPC. K demonstraci funkčnosti jsou použity modely budovy ČVUT-FEL v Praze – Dejvicích.

Aplikace je popsána z pohledu uživatele formou uživatelského manuálu a následně je popsán její vývoj z pohledu softwarového návrháře.

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Chapter 1

Introduction

Buildings as such consume approximately 40% of total energy. Nearly half of that is put into HVAC (Heating, Ventilation and Air Conditioning), hence governments of many states concerned about impacts of this fact on the environment issuing standards, regulating the consumption and promising further savings in this field for the future [36].

There are new houses built incessantly, which comply to these standards, but the number of new buildings compared to the old ones is small and this ratio is changing only slowly, thus engineers are looking for new ways to keep the trend of increasing the savings by changing of structures which already exist.

It is possible to adjust or rebuild a part of the construction to achieve the goal, but this is very costly. Another way of save up is to make the efficiency of energy distribution in current buildings better, which can be done by engagement of Building Automation Systems (BAS) or only by introducing new algorithms for existing ones without an interference with physical aspects of a building. There were efforts of many academic and industrial teams to implement various advanced control algorithms in the area of HVAC [25, 31, 35, 30, 27].

1.1 Advanced control techniques for HVAC

There has been two main directions in the heating control research recently.

One group involves method of the *artificial intelligence*, specifically neural networks, genetic algorithms, fuzzy methods and others.

The second group, which is in concern of this work, employs techniques based on principles of the classical control theory, called *Model Predictive Control (MPC)*. MPC is in theory easy to formulate as it consists in direct application of optimization techniques on the given control problem. It is widely used in many industry areas – see for instance [33, 32, 34, 29] for further reading.

The idea behind *MPC* is to express a goal of the control by the terms of a *cost function*, value of which can be called *penalization*. Minimization of the cost function results in a control strategy, which also fulfils constraints given as a part of MPC problem formulation. This optimization happens on the specific constant time interval, which is called *prediction*

horizon with the length specific for the control problem solved. Specifically for the *HVAC*, the *cost function* is, roughly speaking, equivalent to energy consumed plus penalty for some comfort requirement violation.

The key point, which really differs the technique from others is just mentioned *MPC* factoring of given *constraints* into the control strategy, hence it *predicts* potential future saturations and picks a control trajectory, which both minimizes the *cost function* and does not violate the constraints all at once.

The technique heavily relies on availability of a controlled plant model, which makes the process of plant *model identification* of a great importance.

To cover uncertainties and unpredictable disturbances of the controlled system, there is a need of feedback to be integrated. So in the on-line implementations, the methodology is applied as explained, but only the first point of the optimization result is used as an input to the controlled system. Then in the next sampling period, the optimization is performed again with the new measured data and the whole process is repeated.

1.2 Controlled plant

Specifically for this work, *MPC* is used for control of heating in CTU-FEE building in Prague. Its description follows. Text and illustrations of this subsection are adopted from [36].

Figure 1.1: The building of Czech Technical University in Prague, Dejvice

The building of the CTU uses Crittall [24] type ceiling radiant heating and cooling system. In this system, the heating (or cooling) beams are embedded into the concrete ceiling. A simplified scheme of the ceiling radiant heating system is illustrated in Figure 1.2. The source of heat is a vapor-liquid heat exchanger, which supplies the heating water to the water container. A mixing occurs here, and the water is supplied to the respective heating circuits. An accurate temperature control of the heating water for respective circuits is achieved by a three-port valve with a servo drive. The heating water is then supplied to the respective ceiling beams. There is one measurement point in a reference room for every circuit. The set-point of the control valve is therefore the control variable for the ceiling radiant heating system in each circuit.

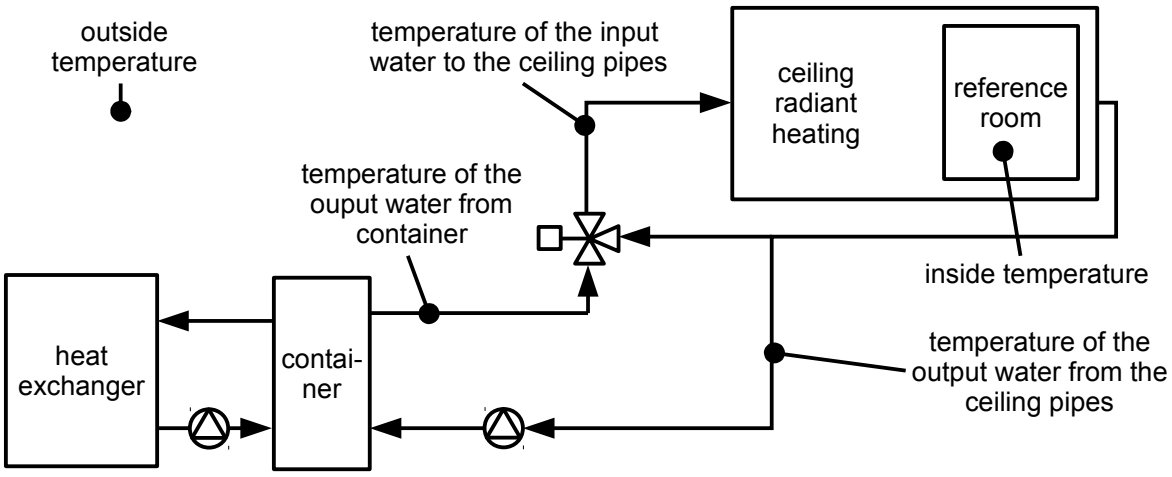


Figure 1.2: Simplified scheme of the ceiling radiant heating system

1.2.1 MPC problem formulation

Direct formulation of the problem of building heating control is:

$$\min_{u} \sum_{k=0}^{N-1} \left(|R_k u_k|_s + |Q_k(y_k - z_k)|_t \right)$$

subject to:

$$\begin{aligned} F_k x_k + G_k u_k &\leq h_k \\ x_{k+1} &= Ax_k + Bu_k + Vv_k \quad k = 1 \dots N_y \\ y_k &= Cx_k + Du_k + Wv_k \quad k = 1 \dots N_y \\ x_0 &= x_{init} \\ \underline{r}_k &\leq z_k \leq \overline{r}_k \quad k = 1 \dots N_y \end{aligned}$$

With these quantities:

- x_k – system state of dimension n_x
- u_k – system input (controlled variables) of dimension n_k
- y_k – vector of system outputs n_y
- v_k – vector of disturbances of dimension n_v
- z_k – slack variable on the zone temperature of dimension n_z
- s, t – norm order of particular parts of the cost function
- x_0, x_{init} – state at time 0, initial state, dimension is the same as for x_k

- $\underline{r}_k, \overline{r}_k$ – minimal and maximal reference variable for the system outputs, dimension is the same as for z_k
- N – prediction horizon, positive integer number
- k – discrete time, integer number, $k \in 0 \dots N-1$
- A, B, C, D – system matrices of appropriate dimensions
- V, W – matrices of disturbance input of appropriate dimensions
- Q_k, R_k – weighting matrices of appropriate dimensions which express trade-off between reference tracking and energy consumption
- F_k, G_k, h_k – matrices/vector, of appropriate dimensions, defining constrains of system states and input variables

This is application of the technique just mentioned. Weighted energy equivalent is penalized in s-norm, while weighted reference band violation is penalized in t-norm. First sharp inequality reflects the physical limits of the system. Second inequality constraints the *slack variable* of reference band.

The *slack variable* is artificially introduced variable, which serves for penalizing given variable, which is attached to, only when it escapes given interval (system output in our case).

1.3 Current controller implementation

At the moment the development of the application started, there was an *MPC runtime (HVAC control system)* established. The controller in this runtime is implemented in MATLAB and takes into account:

- Disturbance predictions – This is a weather forecast, which includes mainly an ambient temperature and also partly a solar radiation power.
- Considers future references – Controller has a knowledge of future requirements of a temperature, which allows it to prepare controller plant for the reference change before it starts.
- Keeps constraints of a plant – Takes into account maximal ratings of all controlled variables (minimal and maximal water temperatures, maximal speed of temperature change).

The system reads input data first. Data is used to formulate the optimization problem, for which YALMIP toolbox [21] is employed. Then a solver is called to obtain the solution. There is mainly sdpt3 solver [15] used, also SeDuMi solver [16] was engaged, but evinced worse results mainly with longer prediction horizons. Computed results are eventually written to disk.

The MPC runtime stores the data and even communicates with PLC using YAML (more in Section 3.5) files, stored locally on the disk of the machine, which performs on-line computations. One of the key points of the application being developed is to emulate this communication and use the system as just described for off-line simulations with only small changes.

YAML files have special structure, convenient for the purpose of the controlling problem. To read the files, there is YAMLMatlab (see Section 3.6) interface used, which implements a kind of inheritance and allows to merge several files into one data structure. Files are organized beginning with the most general level, where for instance the variable classes are defined with their default items (for example maximal temperature). The fields of these classes are then successively specified by another files as needed. For example when there is some element of the class with the maximal water temperature set and this value is different from the one defined in the class which the element comes under, the value is overwritten by the one of the more specific class.

After YAMLMatlab merges the files, the structure is as follows (only important fields stated):

- `variables` – Defines all possible variables which may occur with their default values, constraints, units etc.
- `data` – Actual data, processed by the controller. Important part of the on-line implementation, but not used in the application, because of inefficiency.
- `controllers` – Contains key-value map, which holds settings of all controllers, defined in the system. Each value of this map is another map, containing these key-value pairs:
  - `predictionHorizon` – Prediction horizon length in seconds.
  - `solver` – Specifies which solver is used for computation and its settings.
  - `costFunction` – Key-value map, each item stands for a part, added to the cost function. Adjusts the soft constraints.
    - `norm` – Determines the norm of this cost function part.
    - `weight` – Holds the value of weight of this part.
    - `refMin/refMax` – When set, it sets constant minimal/maximal constraint of the variable, weighted in the cost function. The band between values is not penalized, locations outside are weighted by the value of `weight` field.
    - `refMinSchedule/refMaxSchedule` – Same as preceding, but with a variable constraint. The value is a reference into `data` part of the structure, where the constraint is stored.
  - `constraints` – Hard constraints.
    - `refMin/refMax` – When set, introduces a constraint on the specified variable, which must not be violated by a solver.
    - `refMinSchedule/refMaxSchedule` – Same as preceding, but instead of constant, uses variable as a constraint. The value is a reference into `data` part of the structure, where the constraint is stored.

- `models` – Key-value structure, each item of it holds the information about one model in the system.
- `controlSamplingPeriod` – Sampling period of the model discretization, in seconds.
- `defaultInitialState` – Vector of the state, which the model is initialized to.

In the current HVAC, there is also a script called 'MPC Viewer', which reads the results, and plots them on a web page, which serves as a diagnostic tool for the online process.

Another group of YAML files is used to store the information about which data is plotted and about grouping of these data into charts. The structure of these files is:

- Root of the file is a dictionary with only one key, named `PlotDefinition`. The value under this key is a list, which contains a number of dictionaries. Structure of each that dictionary is:
  - `Title` – Determines the title of the chart.
  - `Variables` – Groups variables, which should be displayed all in one figure. It is a list of dictionaries, each of them with following items:
    - `ID` – Identifies, which variable, specified in YAML definition files, will be plotted.
    - `Color` – Color to plot the series, expressed as a hexadecimal `RRGGBB` triplet.
    - `Description` – Name of the series to be displayed in the legend.

1.3.1 The off-line simulation of the system

Running the system without the connection to the underlying PLC is used to tune the controller, to explore energy savings and to study possible failure of the controller.

The simulations run are short-term, covering the length of the prediction horizon. This strategy of studying the MPC is based on the idea that when the system behaves well on one prediction horizon (typically three or four days long) in all characteristic situations (heating up after a weekend, day-night transitions etc.), this induces that it will be likely to behave well also in closed loop. This is in contrast in long-term approaches (BACTool [3], for example), which evaluate a mean behaviour of the controlled system over a long time in order of months or a year.

1.4 Motivation of the application

When the engineer wants to run a simulation of a control problem, he or she has many possibilities, how to do that. The system plentifully mentioned throughout this work, MATLAB, is only one example.

The problems of these systems are often their complexity, paradoxically their feature-richness, need to learn special kind of de-facto programming language, which cause the novice to be easily lost within.

Mentioned systems are often hard to maintain even for a lecturer during a speech, presenting some control problem and their appearance can be confusing for a speech participants, who can only watch what the lecturer does in addition.

There are some applets and simple tools easily found on the internet, dealing with control engineering branch, even with MPC, but they are all actually textbook examples, with no background in some real specific system, much less with the ability for user to define his/her own control problem in some non-trivial way.

Another aspect is that specifically MPC simulations are known to be time consuming even on some better hardware. Some tool could offer to perform a long-lasting simulation from some very low-end netbook, but with the actual computation distributed to some really powerful hardware, shared with other users of the application. This system could moreover allow the user to run more simulations at the same time, which, distributed on several computation cores, are finished faster than in the case they are run on a standard desktop all at once.

1.5 Basic requirements for the application

The system will be operated using a web browser and, generally speaking, it will allow to launch simulations on some remote computational core (currently MATLAB).

Specifically it will simulate one optimization step of a predictive controller on a defined model-controller (building-MPC) pair from the set, loaded into the system. Subsequently it will give an ability to clearly display the simulation results and especially to explore changes in a behaviour of the controller in the dependency on its settings in an illustrative way.

The work with the software can be divided into two base levels:

Manager level, which will make ordinary people to become familiar with the practice in heating systems design with the MPC method by use of a simple interactive interface, which will in fact allow them only:

- to display a prepared assignment template.
- to change one or at most a few simple parameters of a simulation (for example one number, which for given simulation determines a trade-off between heating comfort and heating cost).
- to launch the simulation.
- to display resulting data series in relation with the system inputs and compare more results with each other.
- to be able to return to the assignment, change some parameter and launch the simulation again.

Engineer level, which will serve to validate mathematical model of the building. The user with an expert knowledge of the building will be able to show that the heating system behaves correctly or poorly with the given conditions. This interface will be more complex, with the functionality approximately same as the previous one, but in addition:

- There will be a possibility to combine various input data series with more freedom and control over the settings.
- It will be possible to fine-tune the simulation settings, especially the weights of particular variable penalization for the MPC strategy.

All results should be some way archived in the user's workspace for further return to the simulations already finished, in the future.

1.5.1 Structure of solved problem

For the purpose of the application design and its clearance, there was a data structure sketched which captures the entities, important for the application. The structure as mapped to the application has following parts:

Prediction horizon This is a constant floating point value in the units of hours, predefined to be between 8 and 168.

Initial conditions Setting, expressed by combobox filled with initial condition sets, defined by administrator. There is also one item crossed out, which means that no initial state will be provided to the simulation and it is in its responsibility to use some default. The initial condition will be mostly an equilibrium or another interesting state.

Constraints This block contains hard constraint settings of the controller. It is a list of variables for which you set the constraint. Each item of this list has minimal and maximal value, which can be each fixed or variable. [1]

Cost function This block is a bunch of cost function contributor variables. For each there can be set:

- **Norm** – 1-norm, quadratic norm and infinity norm
- **Weight** – floating point number higher than zero. [2]
- **Minimal and maximal value** – each can be either fixed or variable as in the Constraints block.

[1] At the time of writing this document, variable hard constraints are not yet implemented in underlying MPC scripts

[2] In current implementation of underlying MPC scripts, there is an effort to normalize weights, so values between 0 and 1 should make the best sense.

Disturbances List of input disturbance variables. Each has variable content – the data series cut-out.

Overall weight This is simply a set of 'One big cost settings' for the whole control problem. When the simulation has the Manager interface set, it is remapped to the weights in Cost function block, which are overwritten by these new values.

User description This is place where you should briefly and clearly describe specifics of your current simulation setting to distinguish between more simulations created from the same template.

Chapter 2

User manual

2.1 Quick start – How to launch the simulation

For the system to be usable, some user should be logged in. Log in by clicking the *User menu* in the top right corner. It is labeled 'Not logged in'.

1. Select **Simulations/Templates** from the main menu.
2. From the list, choose the simulation to run.
3. In the following form, it is possible adjust simulation parameters.
4. To launch the simulation, click the **Compute** button.
5. Wait for results to be displayed.

2.2 Step-by-step guide for an ordinary user

Creating copy, running the simulation, aborting the simulation

1. Choose **Simulations/Templates** from the main menu. The list of templates, visible by you, will appear.
2. Click name of the template you like. For beginning, choose template marked with green **M**, which will lead you to the simpler simulation form. Now you can explore the form, read descriptions and so on.

   If there are some controls on the form, they are greyed out. Moreover there is no **Save** or **Compute** button. It is like this because you are just viewing a template. This template is probably shared by more users and serves as a starting point for their simulations. This is why the template is read-only.
3. Click the button **Work with unsolved copy**. This will copy whichever simulation form you see and sets it up to be your working copy. You are then redirected to

the form of that copy. You will notice that a button bar under the simulation title changed because you are now able to do more with the simulation.

4. Fill in the description. Use something short and clear, say, 'emphasized economy'. Choose some initial condition and use slider to set desired trade-off between comfort and economy – slide it right.

5. Now you want only to save your changes, use **Save** button.

6. Navigate **Simulations/My copies** from the main menu and you will see your newly created working copy there, described with text you entered. You can also navigate the *Template listing* page again and you will notice that the number on the button in the *Copies* column of the template you just copied increased by one. Click the button with the number and you should again see your working copy in the listing. Now use browser **Back** button or click on the working copy *User description* to get back to the working copy form.

7. You want to launch the simulation process now; click **Compute**. This button will save potential changes and then enqueue the simulation for processing. You will be redirected to the *Live computation log*.

8. You can wait for simulation to finish or continue your work. To abort the simulation, click the **Abort** button. You will be redirected back to the simulation form, but the simulation will be marked as *Aborted* and will be read-only. This is because there may be some messages in the computation log and some results already present. To check the partial result and the log, you can click **Result** button in the button bar. But now click **Clear solution** and you have your working copy as you would never have started it.

Displaying results, comparing results

1. Repeat steps 1...4 from the previous list.

2. Now click **Compute** and wait for the simulation to be finished. The *Results* page appears.

3. Pan the figures by mouse dragging, use mousewheel to test zoom. Switch zoom restriction buttons above the figure and explore how this changed the zoom behaviour, click magnifier buttons to perform wheel-less zoom. Finally click button with the crossed circle to reset the view. Drag the figure (in the area near its title) to change the order of figures on the page. This can be useful if you like to quickly see two far figures on the same place.

4. Change series visibility using **Displayed series** dropdown menu. You must click the checkboxes to achieve the effect, not their label.

5. Hide some figures using **Displayed figures** dropdown, located in the button bar under the 'Results' title. For example imagine that you like to compare North and

South supply water temperatures, so switch off other figures, which are not of your interest.

6. Click **Series comparator** on the main button bar. Checkboxes will appear in front of each series label. Turn on checkboxes of series which you like to compare. Remember that checkboxes will remain checked when figure with them is hidden – if you check them and then hide the containing figure to do another comparison, the series from the last comparison will still appear in the comparator window. If you do not like manual unchecking, you can refresh the page, which will restore it to the state just after it has finished.

7. Click **Compare selected** button and the *Series comparator* modal window will appear. The figure inside behaves like any other figure and displays the series you selected in the previous step.

Using the engineer presentation

1. Follow the first step of previous list with the difference that you choose some template marked by blue **M**. Now you are working with the *Engineer presentation* of the simulation.

2. Choose some initial state. Simple edit fields does not deserve some additional comments. But it would be boring if all references and disturbances would be constant. So change *Room temperatures* from the *Cost function* block to both have have variable minimum and maximum (choosing this in appropriate comboboxes), choose the appropriate data series from another just-appeared combobox for them – it will be named in some clear manner (typically it will contain the word 'reference' and specifier 'min').

3. Click the button with bar graph to initiate the *Graph picker*. At this time only turn on some coloured synchronization button, say, green one and close the picker. Time points are synchronized by *pushing* the value selected at the moment the picker is closed to all others, synchronized by the same coloured button combination. Not *pulling* it from lastly selected. So if you choose the starting time now, you will loose your selection.

4. Repeat previous step for all series, which are somewhat related to each other (all references).

5. Now open some reference graph picker, for which you just selected the sync combination. You can deal with the graph as the ones on *Results* page. If you need to, zoom to the part which you want to choose, click button with the pencil and then in the plot area. Green selection appears with its beginning in the point where you clicked. Or choose the point from the *Calendar picker* clicking the edit box with the date and time. When you close the picker, it will publish its value to all subscribers with the same sync signature.

6. Time point selections are persisted including the state of synchronization buttons, so do not worry, if you need to do this 'clicking procedure', you probably will have to do it only once. Persist the form using the **Save** button.

7. Do the same steps for disturbances if there are more than one.

8. Launching the simulation is exactly the same process as described above.

Running multiple simulations, checking the queue

If you need to compare more simulation results, you will probably feel the advantage of having more workers able to deal with your tasks.

1. Start some simulation. The knowledge of how to do it can be found in previous lists.

2. When you are in *Live computation log* do not wait for the simulation to finish. Set up another simulation using the main menu. Better said: Repeat from the first step until you have enqueued all simulations you wanted.

3. You probably noticed white 'play' arrow, which appeared on the right side of the **Simulations** menu. Whenever the arrow is there, it means that you have some tasks in the queue or some tasks just being computed on workers or both. When all your tasks are done, the arrow disappears. This will happen when you navigate to another page or automatically – the arrow state reloads itself every 30s.

4. If you have feeling that the computation takes too long, you can go for **Processing/Task queue** to see where in the queue you are. You can look for your user name in *Owner* column or just look for content of *Task* column, which has a blue colour. This means that the task is accessible by you hence it is probably your task (unless you are an administrator – in that case, all tasks are yours in principle).

5. When all your tasks are finished, you can display their results all at once to be able to compare them. Go to **Simulations/My results**. Sort the list clicking the *Last touched* column twice in order to sort it descending by the time when tasks were finished.

6. Choose tasks for result comparison turning on appropriate checkboxes on the left.

7. Click **Show results at once**, which will navigate you to the *Results* page, where you can see results of all simulations selected. Now use techniques you learnt in previous listings.

   To revise: Hide resulting figures of all simulations you are not interested to. After this step you will probably end up with simulation result block with one figure per one simulation. Turn on the comparator and select series to compare. Then launch the comparator dialog.

2.3 Step-by-step guide for an administrator

Adding users and groups

The concept of users and groups in Django and so in the application is probably the same you are used to. Groups are utilized basically to associate more templates to more users in some comfortable way.

1. Select **username/Django admin** from the main menu, where **username** is the name of the user currently logged in and there must be the sign **(SU)** after that name, which indicates that the user is a superuser, otherwise the **Django admin** choice will not be displayed. In the admin interface, choose **Groups**.

2. Create one group using **Add user** at the top right corner of the window.

3. Go to admin home (link at the top left corner of the window) and click **Users**.

4. Now you see the listing of all users registered in the system including additional information about them. Add several users using **Add user** at the top right corner of the window. Users you now added are ordinary users.

5. In the listing, click on each username of newly created users and in *Groups* block select the group you just created. Then click **Save**. If you like to make the users being administrators, check *Staff status* and *Superuser status* for them. But do not activate this now, we need just ordinary users for the next instruction list.

Publishing templates to users

1. In Django administration, click **Generic problems**, then click on the simulation you want to associate. The page you just navigated to can be also navigated from the simulation form using **Administer this simulation** or from the listing of simulations clicking the button with the icon of gear.

2. In the administration page of simulation, choose group you created in steps of previous list in the *Viewer users* block. Additionally you can afterwards create yet another users and associate them some simulations individually in the *Viewer groups* block. At the end of each modification click **Save**.

3. Log out and then log in as some user you created. Check that he or she can see simulations you associated him or her and that he or she can operate with them.

   Remember that if you have turned on the *is public* flag of some simulation, this simulation will appear in the listing of templates of every user (if it is a template) even if you have not explicitly associated it. In addition if you set *is public* flag for working copy (solved), it will appear in the listing of working copies (plus in the listing results) of the associated user. The user then will not be able to delete it because he or she will not be owner of this simulation (unless you set the user to be the owner), which might be confusing for him or her.

4. If you want to cancel all associations to users or groups of more templates, you can do that as a bulk operation. In the Django admin, go to the Generic problem listing, turn on checkboxes belonging to the simulations you like to cancel associations for and then use appropriate action from the combobox labeled **Actions**, located above the listing and click **OK**.

Setting up a template

When simulations are inserted to the system, they are set to some default state. The script, assimilating the simulations, will make an effort to set up the simulation for you, using supplied YAML files by setting weights, norms, prediction horizon, constant maxima/minima and so, but will not be able to infer some details, for example which disturbance and from which time you like to choose.

The approach to fine-tune the simulation follows.

1. Choose some template you want to set up. Go to its administration. You learnt the knowledge of how to do so in previous instruction listings. You do not need to choose a template, every simulation can be turned into a template and back, which ability we will now utilize.

2. On the administration page, uncheck **Is template** flag and set **Presentation** to **Engineer**, which will consequently allows you to edit largest possible set of parameters. The parameters will be still there if the choosen *presentation* will be finally *Manager*. The key is that *Manager* presentation will hide the parameters, but use them all as a resulting problem set-up unless something (some weights) gets overriden by *overall weights*.

   Just for case, remove all associations the simulation may have to users and groups.

   Click **Save and continue editing** at the bottom of the page, then **View on site**, which will lead you to the simulation form of the problem.

3. Set simulation parameters as you like, run several iterations of its computation to check whether you set it correctly. Then clear the simulation results. Remember to **Save** or **Compute** the simulation to persist changes you made.

4. Optionally – if you plan to make the simulation presentation to be *Manager* – go to the administration page of the simulation and select *Manager* presentation. Then again **View on site**. Now choose the default state of *Overall weight* sliders, then – again – do not forget to persist the changes.

5. Finally go to the simulation administration again and check **Is template** there. Additionally you can associate it some descriptor.

   You now have your brand new template. Associate it to some users, log in using their accounts and see whether it works as expected.

2.4 The application in general – Ordinary user point of view

2.4.1 Introduction and base terms

The application basically allows the users to work with some simulation – to set it up, launch it and explore its output. It can especially be used to iteratively run the same simulation, tune selected parameters and track results evolution.

2.4.2 Overall architecture

The cornerstone of the system is the web interface, expressing the simulation backend in a non-expert accessible way. Next noticeable part of the system is the task queue, making the application asynchronous. The optimal control problems, solved by the system are typically quite time consuming with a need of a special software (MATLAB in our case). This led to an establishment of a mechanism, which in fact delivers the power of MATLAB to the user's web browser and in addition allows the user to run more tasks simultaneously. Tasks are temporarily stored in FIFO queue and are taken by one of computation cores as the core is free. User can then immediately continue by setting up the next task even though the first one has not yet ended.

2.4.3 Templates and Working copies

The system is built on the concept of templates and working copies. An administrator creates a set of templates and associates them to particular users, who can then use them. The ordinary user can then take a look at the templates, which have been associated to him or her, choose one, set its parameters and launch it. To use a template means that the user creates a working copy of the template. This copy becomes his or her private working place, where he or she can set various parameters, run the simulation using these parameters and finally explore the results produced by the simulation.

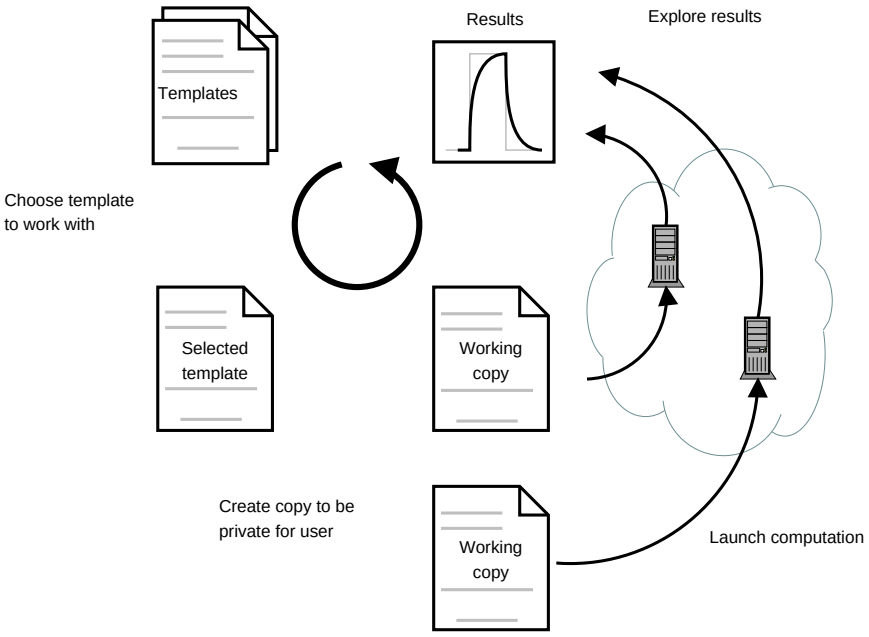


Figure 2.1: Simplified application workflow

2.4.4 Simulation states

Each simulation goes through a simple lifecycle, which has following states:

Unsolved At the time user creates the working copy, the state is set to Unsolved. This is the only state, which allows user to edit the parameters of the simulation. Other states may signal presence of partial results and log items, which would not be consistent with saved changes in simulation settings, hence other states disable saving and launching of the simulation.

Enqueued When the simulation is launched, its state is changed to Enqueued. This means that the task was pushed into the task queue, but not yet received by computation core.

Solving As the core receives the task, its state is changed to Solving.

Finished After the simulation run, the state is set to Finished. This happens also in case of an error, raised during the simulation. You can find out whether the task finished normally or due to an error in the computation log.

Aborted There is also one more state – Aborted. There are more reasons for the task to be aborted – the task is aborted when it is enqueued longer than its *enqueued timeout* or is processed longer than its *processing timeout*, but as for user, the most obvious reason is hitting the **Abort** button on the *live simulation log page* – see Section 2.6.11.

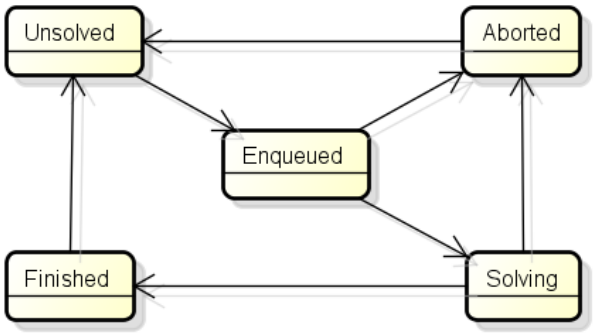


Figure 2.2: Possible states of a simulation

2.4.5 Simulation presentations

The simulation can be expressed to the user in several ways. Currently there are two:

Manager presentation This one shows only user description, initial conditions and overall weights. It is meant for people without an expert knowledge of the building, just to see how the trade-off between comfort and cost influences resulting system behaviour of the heating. Overall weights will be used to create Cost function weights as explained above. The mapping is created by an administrator at the time the simulation is inserted into the application. Other settings, mentioned in Section 1.3.1 are hidden, but are still present and serve as a predefined simulation settings.

Engineer presentation This interface is more complex and shows user description, initial conditions, constraints, cost function and disturbances. This is a place for sophisticated experiments with the simulation.

2.4.6 Running the simulation

When you set all parameters to the desired values, you can launch the solver. This action does not directly call some numerical routines. Instead, it enqueues the simulation into the queue, common for all users, where it waits for some free-for-use computation core. You can watch the log, informing you about the simulation state or you can experiment with another setting or another simulation.

2.4.7 Results

When the simulation finishes, results can be viewed. Results are presented in a form of charts, where related series are displayed in the same figure. You can view only particular data series, you can compare two or more series, which are not related. The result view can show results of more than one simulation at the same time and allows to do these comparisons over more simulations.

2.4.8 Simulation visibility

There can be simulations of more distinct systems or of a different kind in the application. For the user not to be lost, while seeing all simulations in the system, there are some relations between users and simulations possible. Moreover it is a good habit to found some security rules, even simple, to increase user comfort (specifically others will not silently change your simulation parameters and clear results and so on).

When you log in, you see only simulations, which were assigned to you by an administrator plus you see results and working copies, you have made.

After login you can typically see the list of templates, of which you have a read privilege, because an administrator created a viewer relation between you or your user group and these templates.

As you create a working copy, you are becoming an owner of the copy, which gives you write access and allows you to enqueue it for computation.

2.5 The application in general – Administrator point of view

2.5.1 Simulation visibility

One of the most noticeable differences that you are behaving as an owner to all simulations present in the system. That means you can view, edit, launch and abort foreign simulations.

2.5.2 Administrator interface

The next big difference is that an administrator has access to the admin area, where some additional settings of the system can be changed:

- Add, delete and change users and join them to groups.
- Add, delete and change user groups.
- Change some properties of simulations:
  - Rename and delete.
  - Assign template to users or groups.
  - Change user description.
  - Create, delete and assign simulation descriptor (simulation parameter legends, general introduction).
  - Change public flag of the simulation (turning it on make the simulation visible for all users, even anonymous).

- Change template flag of the simulation (turned on makes the simulation behave like a template).
- Change simulation presentation (Manager, Engineer).

2.6 Walk through the application

2.6.1 Top menu

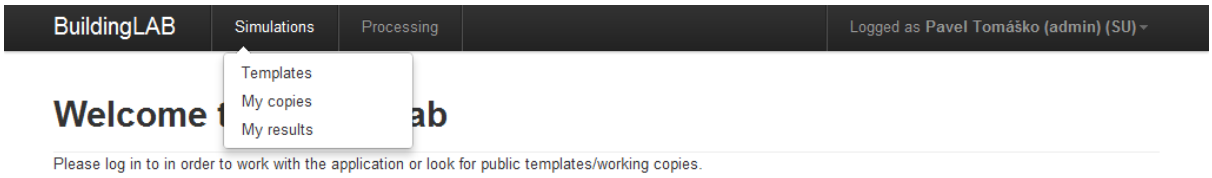


Figure 2.3: The top menu

This menu is present on all pages except the description page. It contains a couple of useful links:

- **Simulations**
  - **Templates** – List templates visible for currently logged user. See Section 2.6.2.
  - **My copies** – List all working copies visible to the current user. More in Section 2.6.3.
  - **My results** – List all simulations, marked as Finished. Read more in Section 2.6.4.
- **Processing**
  - **Task queue** – Display tasks waiting for processing and tasks just being processed.
  - **Workers** – Show online computation cores.
- **User menu** – 'Not logged in' or *username*
  - **Log out**
  - **Django admin** – for administrator only

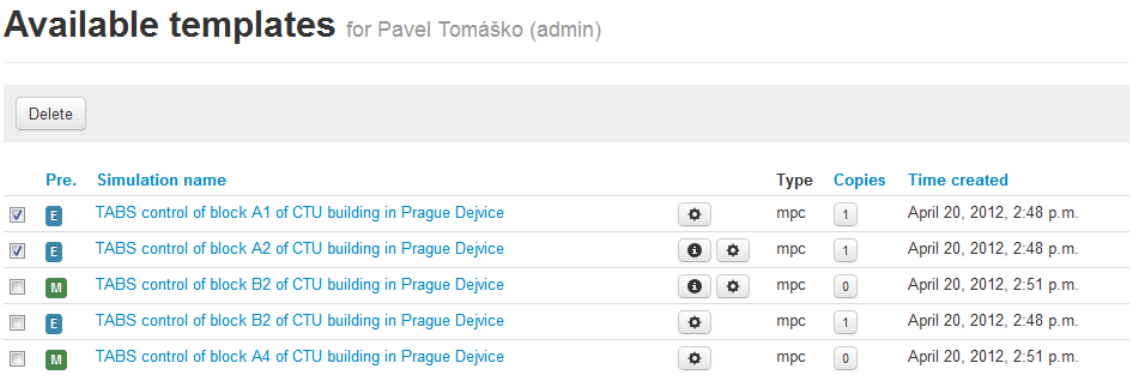


Figure 2.4: Templates listing

2.6.2 Template list

Here the user sees which simulation templates are accessible to him or her. If you are an administrator, you can use checkboxes on the leftmost side of the table and delete them clicking the **Delete** button. Beware that this removal will cascade on every copy created from this template so users can loose their results. If you do not like this behaviour, use the administrator interface, which will not perform cascaded deletion.

The **Pre.** column lets you know which presentation type is used for the template. **M** stands for **Manager view**, **E** stands for **Engineer view**.

Clicking the item in the **Simulation name** column will open given template.

Next to the Simulation name column is place with buttons for additional actions: Button with little gear is visible only when you are an administrator and will navigate to the administrator interface for given simulation. The button with the '**i**' letter will appear when the simulation has a description page assigned and navigates to that page.

Application is designed to be able to work with more simulation types than only MPC. In case you implement a new type, you can distinguish it from others by the **Type** column.

The **Copies** column includes buttons, whose label equals of the number of working copies of that template, belonging to the logged in user. Clicking one of these buttons displays the list of working copies.

The last column says when the simulation was last saved.

2.6.3 Working copy list

The list includes working copies, which are owned by the current user. The columns are same regardless the place from where the list was navigated to (Working copies can be navigated from the template list, from 'My copies' and 'My results' items from the 'Simulations' menu and by 'Working copies' button in the simulation form).

Checkboxes on the left side allows the user to select simulations for bulk operation. **Delete** button serves for the obvious reason. Just remember that the deletion will also cover results of the selected simulations and the action cannot be undone.

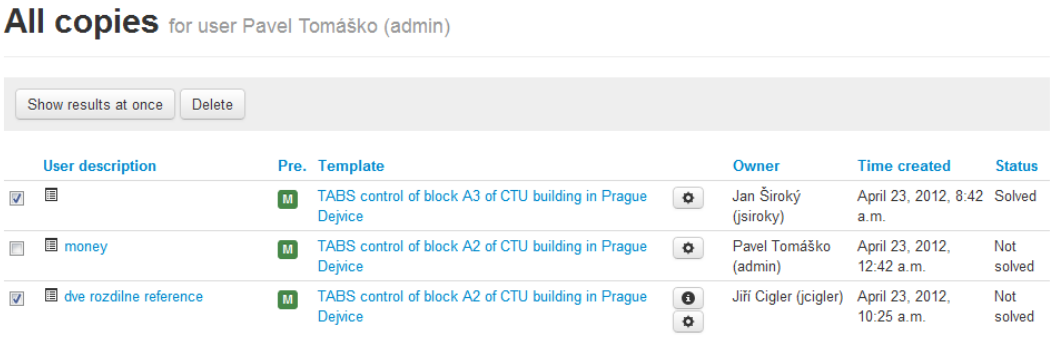


Figure 2.5: Working copies listing

There is one more button for bulk operation – **Show results at once** – which is particularly useful for comparing results of more simulations.

The simulation form of the working copy is viewed clicking on a label or an icon in the **User description** column. Every simulation has associated the user description text block, which serves as a 'fine identification' of every simulation. If you do not fill in the **User description** field and create for example ten copies from the same template, you will easily loose control over which is which.

Pre. column was described in section 2.6.2.

Clicking an item in **Template** column will navigate to the template of the given copy. Remember this difference from the **User description** column, which leads to the actual copy. Especially when the user does not annotate his or her simulation with *user descriptions*, it is easy to click the **Template** column instead of the **User description** column and copy the template instead of the existing copy by an accident. So try to annotate your simulations when possible.

Right of the **Template** column is place for additional operation buttons, which are the same as described in section 2.6.2

The information about who created the copy is found in the column **Owner**. The user, who is not an administrator will probably find here himself or herself in most cases.

Time created column says when the particular copy was made.

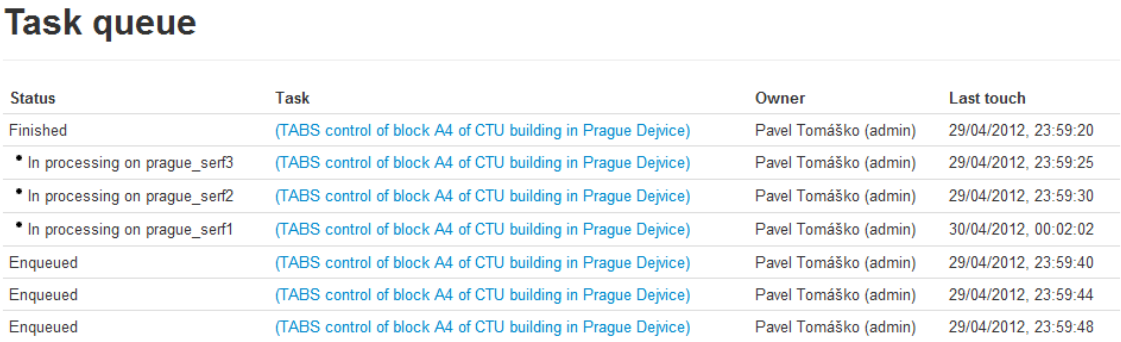
Status column indicates what is happening with the simulation. Used terms, which might appear in there are described in section 2.4.4 with the difference that the state *Solving* is named *Processing on worker_name* instead with *worker_name* being the identification of the core, which deals with the computation.

It is worth mentioning that this page is not 'realtime', e.g. when you find the status here saying that the task is in processing, this label will not change until you manually refresh the page. There are more pages containing some information which is expected to change anon but are not refreshed automatically. These pages have the footer saying when the page was generated which was an effort to hold the displayed data consistency without the need of having each odd page auto-reloaded.

2.6.4 Result list

This page looks the same as the one showing working copies of the user, but the content is filtered to show only *Finished* and *Aborted* simulations.

2.6.5 Task queue



Task queue

Status	Task	Owner	Last touch
Finished	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	29/04/2012, 23:59:20
• In processing on prague_serf3	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	29/04/2012, 23:59:25
• In processing on prague_serf2	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	29/04/2012, 23:59:30
• In processing on prague_serf1	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	30/04/2012, 00:02:02
Enqueued	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	29/04/2012, 23:59:40
Enqueued	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	29/04/2012, 23:59:44
Enqueued	(TABS control of block A4 of CTU building in Prague Dejvice)	Pavel Tomáško (admin)	29/04/2012, 23:59:48

Figure 2.6: Task queue listing

As the title says, this is the view of the task queue. Specifically you can find here: enqueued tasks, task in processing and done tasks for five minutes since the time they were finished.

The meaning of column **Status** was described in section 2.6.3.

The **Task** column contains items of the form: *user description (simulation name)* and each one navigates to the given simulation form.

Simulation has its **Owner** from the time it was created as a working copy. This consequently indicates who enqueued the task.

The **Last touch** field informs about the time when the state of the simulation was changed. For example when you see *Enqueued* in the **Status** column, this column gives the time when the task was enqueued and so on.

2.6.6 Online cores

This is the overview of workers available in the system an their current jobs.

The **Type** column is actually matter of possible future. It is planned to implement one additional type of 'equipment' connected to the BuildingLAB queue, which is meant to be a *computation core starter*.

Identifier is the unique string, which distinguishes one worker from another.

The **Last sign of life before** column is maybe relic from the past when the timeouts have not yet been implemented and there was a need to see whether are workers are 'properly alive'. The value in this column determines when the application 'heard' about the core for the last time. At the moment, the worker record is automatically discarded when it does not send any message for 30 seconds.

Figure 2.7: Online cores listing

For **Status** maybe the name says everything. Possible values are *Idle* and *Busy*. Here should be noted that when there is a task just being processed by the worker and currently logged user has a right to view it, the *Busy* status will be displayed as a button and will navigate to the just-being-processed simulation form.

2.6.7 Simulation form

All simulation forms have some common parts. There is an info about its state and underneath is a button bar. Its content is different according to the current simulation state. There can appear following buttons:

- **Clear solution** – Clear result and log of *Finished* simulation and set its state to *Working copy*.
- **Results** – Open result page of finished simulation.
- **Save** – Persist changes made in the form.
- **Work with unsolved copy** – Copy the current simulation and navigate to its form. If the the current simulation is solved, copy it without solution as a *Working copy*.
- **Work with copy from original** – Create a copy of the template which was used to create current simulation.
- **Go to original** – Open the template which was used to create current simulation.
- **Working copies** – Show all working copies from current simulation.
- **Compute** – Enqueue the simulation for processing.
- **Computation log** – Show live computation log.
- **Administer this simulation** – Navigate to the administrator page for current simulation.

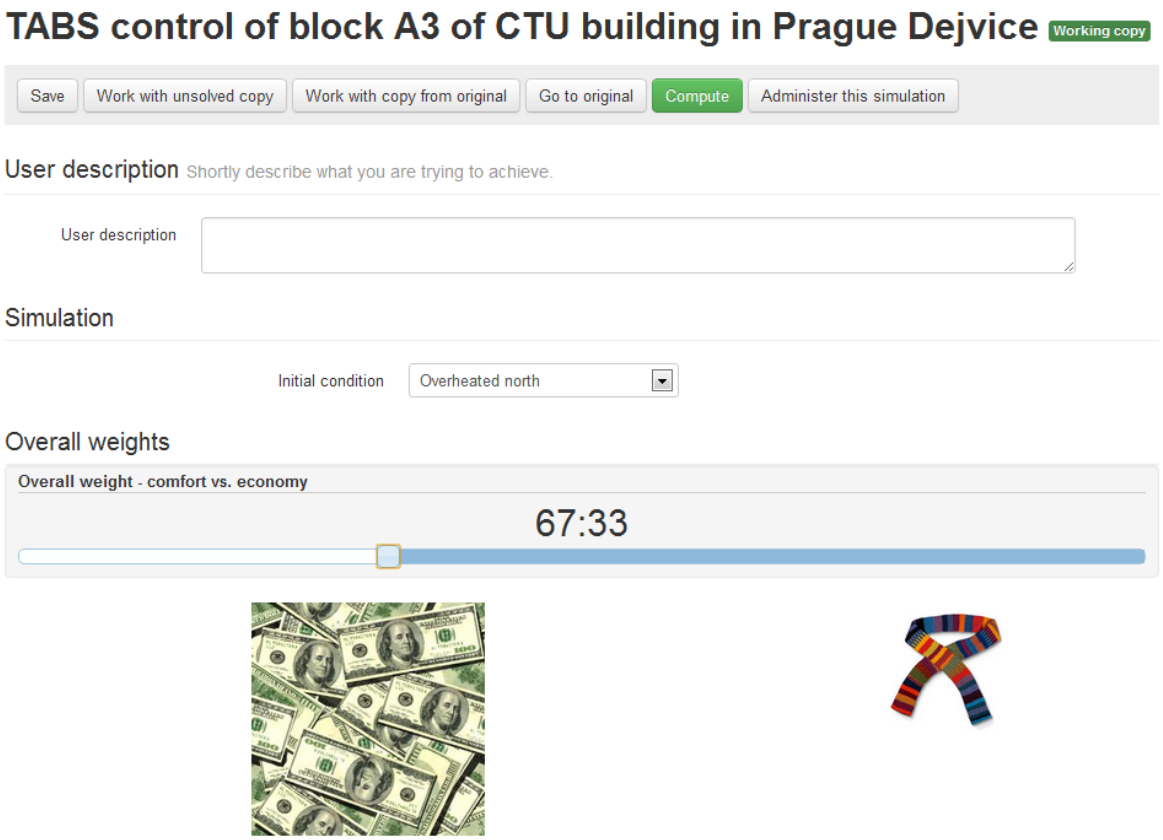


Figure 2.8: The manager view

Underneath the bar you can find the text area to fill in your description. Fill in something which describes what you changed in the form or what you are trying to show using your simulation. Remember that first 128 characters of this field will appear in *User description* column of table displaying working copies (Simulation listings and Task queue) and you will use this description part to identify the simulation.

2.6.8 Simulation form – the manager view

Picture of the view was placed in the previous section. As said earlier, the specific of the manager view is its simplicity. So the only parameters the user can change here are *Initial condition* and *Overall weights*.

The latter is set using the slider and graphical illustration of trade-off between comfort and economical aspects of the problem.

2.6.9 Simulation form – the engineer view

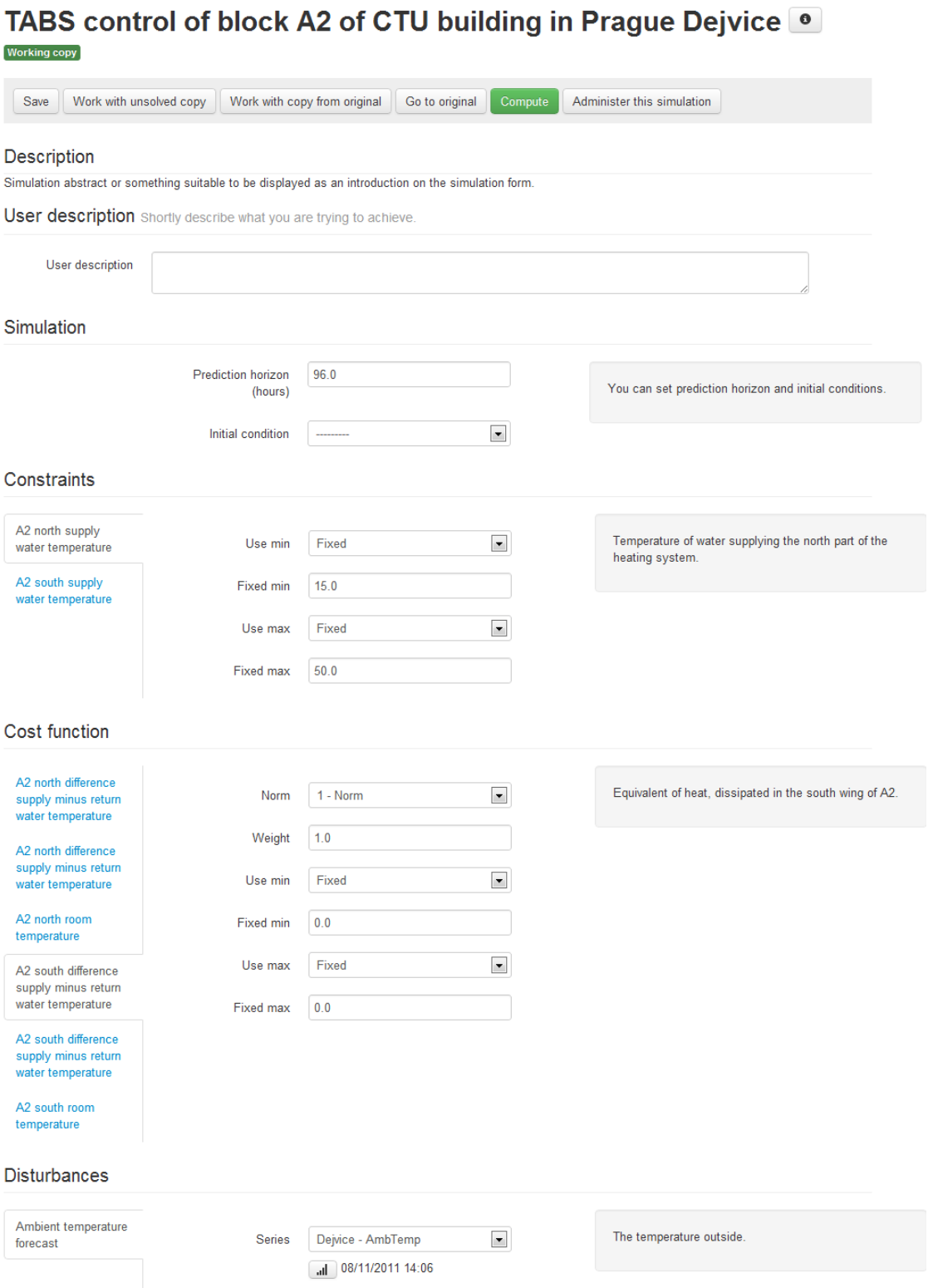


Figure 2.9: The engineer view

The engineer view can be a bit mind-blowing place, but it is nothing complicated in principle.

You see controls already known from *Manager lab*. There are many extra controls, so it is possible that you will see help bars on the right if the administrator set them up, which should explain content of each part of the form.

Best way to explain how does the form behave is perhaps to use the example as seen on the picture 2.9.

The *Simulation* block is self-explanatory. The prediction horizon setting is constrained as written in section 1.3.1. The *Initial condition* field is set to some concrete value, which will be used during simulation initialization.

More interesting are the following blocks, which are tabbed to be able to change more settings of the same kind – one tab per one constraint, one for each cost function addend and the same for disturbances.

The *Constraints* block denotes hard constraints of the solved problem. Fields are functioning almost the same as in next two blocks. Basically if you see the combobox starting with word *Use*, the variable can be of both constant and variable content. The appropriate field will change from simple edit to graph picker and back as you change the *Use...* field.

There is a minimum of 'A2 north supply water' set to be fixed with value specified to be 15°C. Maximum value is set to be variable and you see that this choice changed an edit field for fixed value to combobox for data series selection – in the case on the picture the series 'Reference – max room temperature' is used and finally there is graph picker – small button with bar graph icon with text showing date and time of the starting point currently selected (08/11/2011 14:06 in our case). By clicking the button the picker is launched, which will be explained in detail in the following section.

The *Cost function* block is functionally same as the *Constraints* block except for having a *Norm* combobox and *Weight* edit field in addition. This block introduces soft constraints of the problem.

There are simulation inputs expressed in the *Disturbances* block can be only variable, because constants would not have much sense for this purpose.

2.6.10 Data cut-out picker

This modal window as shown in picture 2.10, allows you to explore how does the data series look like, zoom to see its details and pick the time interval, which will be used as the input to the simulation.

Graph navigation You can move the graph using mouse by drag&drop. Zooming is performed using mousewheel. Three leftmost buttons on the graph toolbar change the zooming behaviour – they set the direction in which the view is zoomed in and out. Follow the icons.

The buttons with magnifier are for zooming without using the mousewheel. The main reason for introducing them was that the graph component used has a bug reading the

mousewheel in some browsers, so when the mousewheel will not do as you expect it to du, use these buttons instead.

The purpose of the button with crossed circle is to reset view to the default in case you 'loose yourself' during exploring. This can easily happen due to mousewheel bug mentioned above, which by an accident sets the zooming parameters to such values that the data cannot be displayed anymore using zooming and panning operations.

There always is a red data cursor, which allows the user to measure exact values found in the figure. Measured values are updated on every mouse move and displayed in the left top corner of the plot area.

Time period selection Turning on the toggle button with pencil causes that every mouse click in the graph area will move the starting time point to the location when the user clicked. Time selection is represented by green area in the graph, its length is automatically set to be the length of prediction horizon. For better explanation see picture 2.11.

There is also possibility to choose the exact starting point using the datetime picker as seen on picture 2.12.

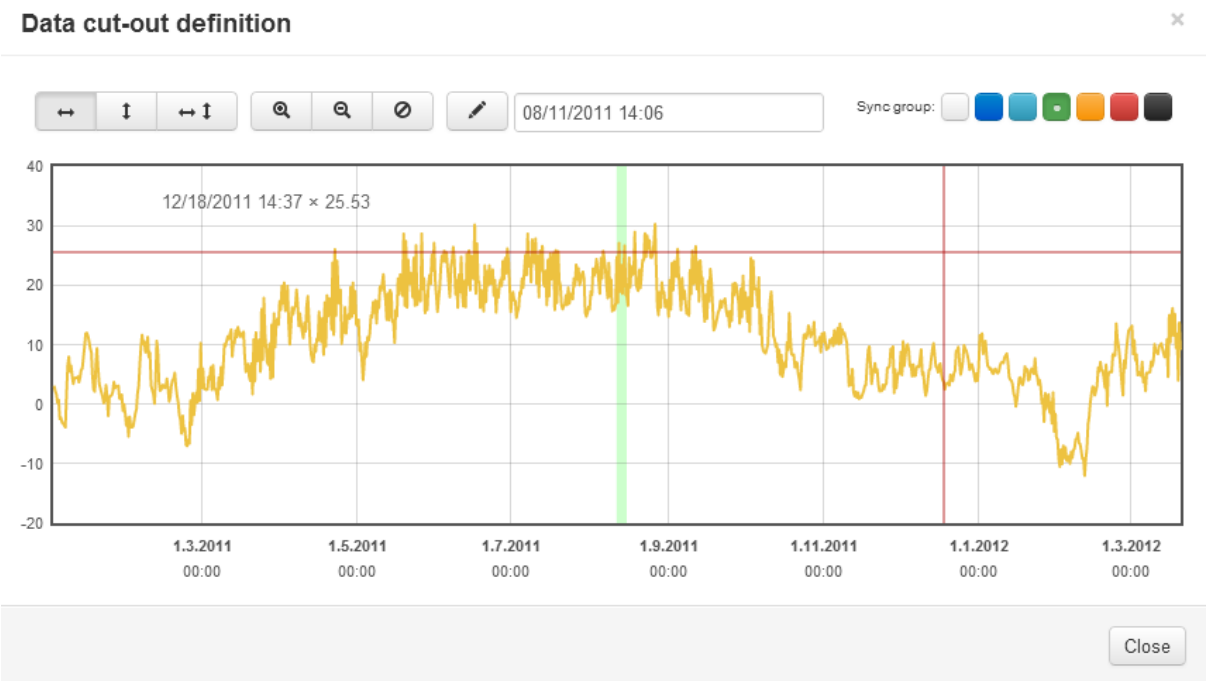


Figure 2.10: Data cut-out picker

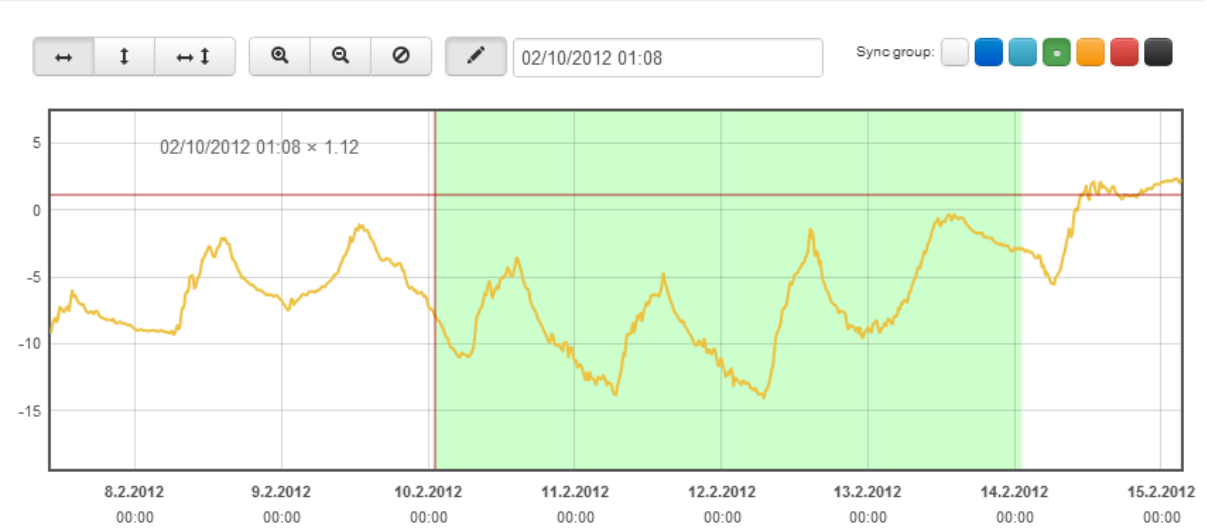


Figure 2.11: Data cut-out picker – zoomed to better see the selection

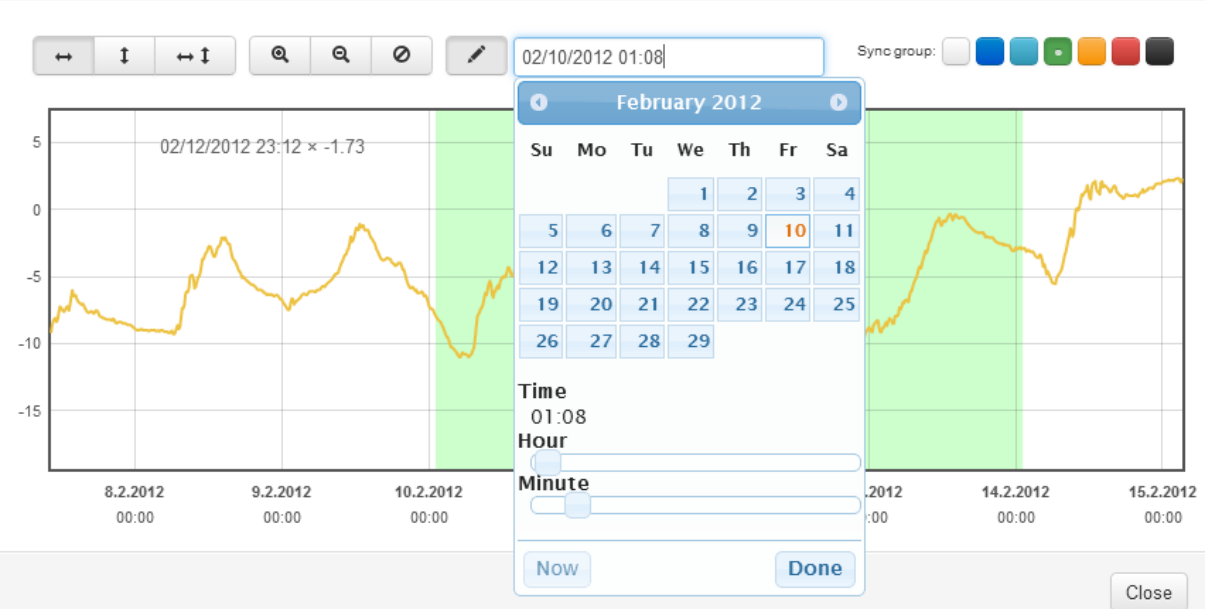


Figure 2.12: Data cut-out picker – the calendar picker

Data series synchronization There is one more noticeable feature in the picker window – the starting point synchronization. It is performed using colored toggle buttons located in the top right corner of the window.

If no button is selected, the picker will neither do nor be under any synchronization.

If the user checks one or more of the toggle buttons, then as soon as you close the window with these buttons checked, every other series cut-out component on the simulation form – even hidden one – with the same colour combination checked will be set exactly the same starting time value.

This is very useful feature when you need to select the starting point for two or more series, which are some way related as for example minimum and maximum value, maybe some disturbances and so on.

You can very well manage with exactly only one button checked. Buttons could easily be radio buttons instead of checkbox-type ones, because the checkbox implementation allows you to set up to 128 synchronization groups for one simulation form, which is certainly more than you need in the whole system. Checkboxes just for fun.

On all pictures, there is a green button switched on.

2.6.11 Computation log

Time	Type	Message
April 30, 2012, 22:16:58	INFO	Task enqueued.
April 30, 2012, 22:17:01	INFO	Delivered to prague_serf1.
April 30, 2012, 22:17:01	INFO	Task dequeued.
April 30, 2012, 22:17:01	INFO	Assignment downloaded, starting script: 'BLDejviceMain.
April 30, 2012, 22:17:02	DEBUG	View record
April 30, 2012, 22:17:03	INFO	Downloaded 2 input series.
April 30, 2012, 22:17:03	WSNAPSHOT	Workspace snapshot taken, download here.
April 30, 2012, 22:17:03	INFO	Calling SolveMPC.
April 30, 2012, 22:17:03	WSNAPSHOT	Workspace snapshot taken, download here.
April 30, 2012, 22:17:04	INFO	SolveMPC: Formulating problem.
April 30, 2012, 22:17:18	INFO	SolveMPC: Problem formulation successful, calling solver.
April 30, 2012, 22:17:32	WSNAPSHOT	Workspace snapshot taken, download here.
April 30, 2012, 22:17:33	INFO	Uploaded 13 output series.
April 30, 2012, 22:17:33	INFO	Script finished.
April 30, 2012, 22:17:33	CLOSURE	Worker session finished.

Figure 2.13: Computation log

When you click the **Compute** button, you are redirected to the page showing *Live computation log*. Here you can watch what is happening with your simulation, the table containing log is polled every few seconds.

The same log view is obtained on the page of results after the computation finished after clicking **Computation log**.

Again, it is best to describe this using the example. See Figure 2.13.

The meaning of columns is obvious. Possible log record types are:

- **Info** – Just says something to let user know that the process did not hung.
- **Error** – Informs that the worker script raised an exception, which was unhandled. The exception is serialized and shown in the log, in form similar to the way how it is displayed in MATLAB.

- **Debug** – This will probably contain dump of some MATLAB variable or structure, which will be displayed after clicking **View record** in the *Message* area.
- **Wsnapshot** – Signals that whole workspace has been just saved. The *Message* area then contains the link, where `.mat` file can be downloaded and further be used to track scripts action in case of an error or for an interest.
- **Closure** – This is mostly the last message of the log. It says how exactly the computation was finished.

2.6.12 Results page

When the task is done it is possible to show its results. It happens automatically when the user has the *Live computation log* displayed at the moment the simulation finishes, which then causes the user to be automatically redirected to this page, otherwise the user can open it from some page that contains working copies list by clicking an item in *User description* column or clicking the **Results** button in the simulation form.

This page can show results of more than one simulation. In that case the results are viewed one after the other – just imagine the page on the figure repeated several times with different data.

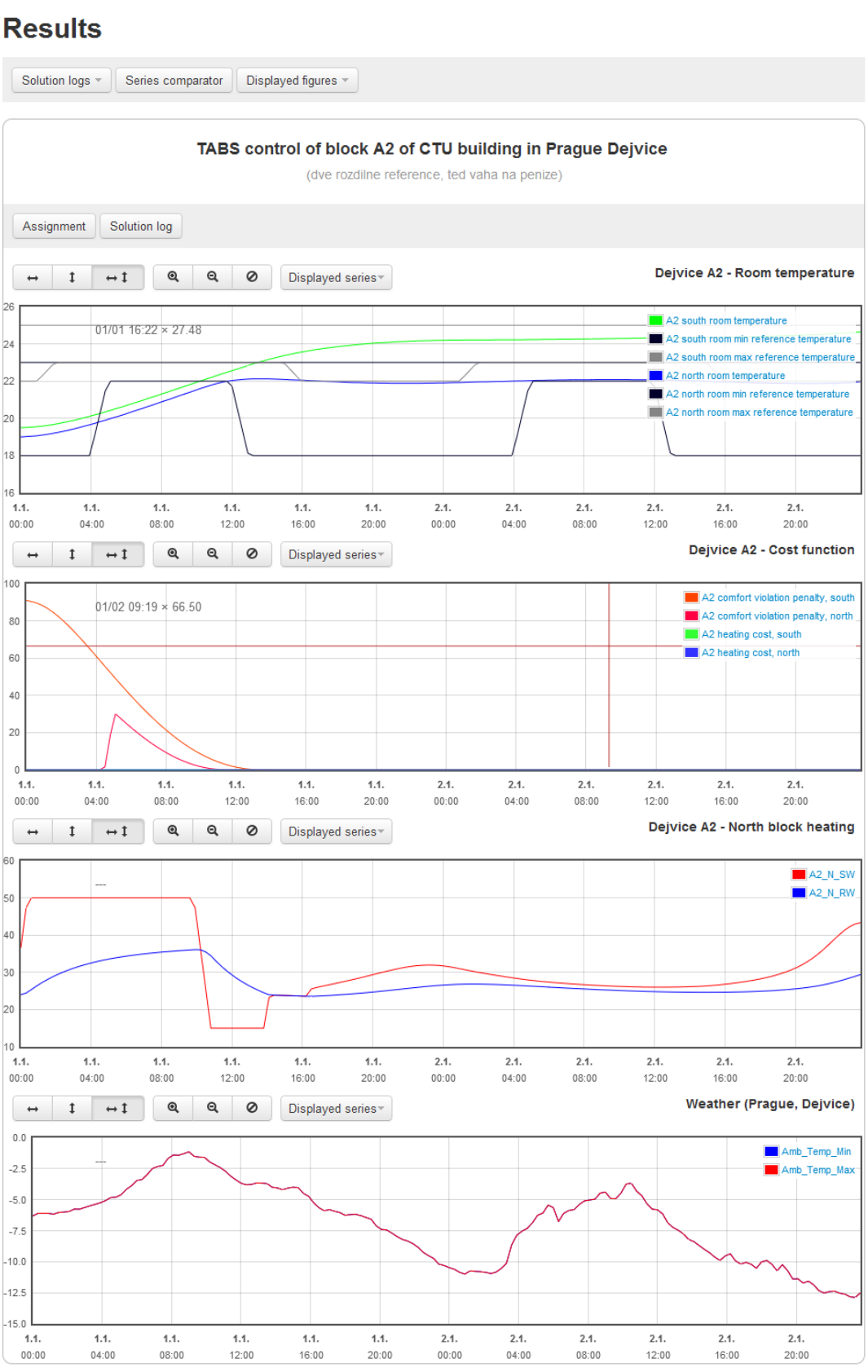


Figure 2.14: The result page

To describe buttons under the 'Results' title:

- **Solution logs** – Drops down a menu whose items correspond to shown simulations and clicking one of them causes displaying modal window with the solution log of the chosen simulation.

- **Series comparator** – Turning on this toggle button, checkbox appears before each title of displayed data series in the legend. There also appears button **Compare selected** beside the button just turned on. Checking some data series and clicking the **Compare selected** button, the user fire the *Series comparator* modal window, displaying selected series all in one graph as shown in the Picture 2.16.

- **Displayed figures** – This is a dropdown menu where the user can restrict the set of displayed figures only to those important for him or her. The dropdown contains identifiers of all figures divided into groups as shown in the Picture 2.15.

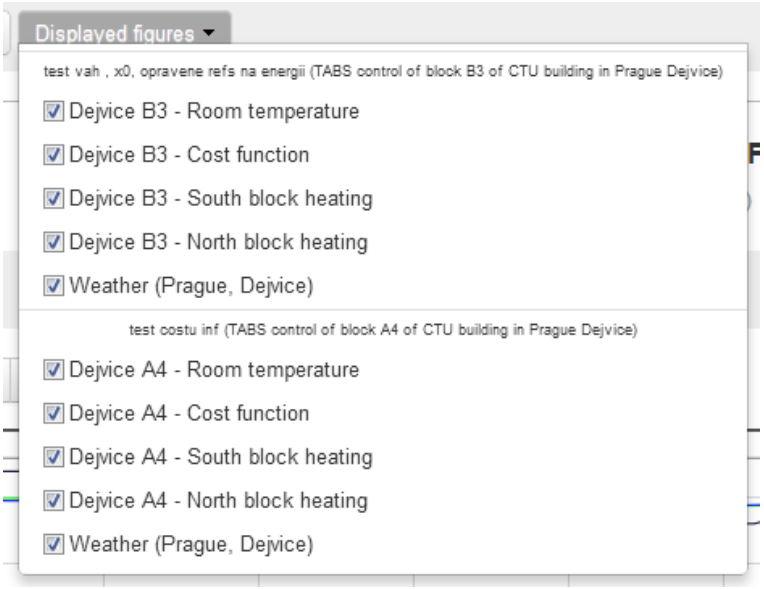

Displayed figures
test vah , x0, opravene refs na energii (TABS control of block B3 of CTU building in Prague Dejvice)
Dejvice B3 - Room temperature
Dejvice B3 - Cost function
Dejvice B3 - South block heating
Dejvice B3 - North block heating
Weather (Prague, Dejvice)
test costu inf (TABS control of block A4 of CTU building in Prague Dejvice)
Dejvice A4 - Room temperature
Dejvice A4 - Cost function
Dejvice A4 - South block heating
Dejvice A4 - North block heating
Weather (Prague, Dejvice)

Figure 2.15: Dropdown menu for selecting displayed figures

The behaviour of figures is very similar to the *Data cut-out picker* described in section 2.6.10 – with the same meaning of buttons above the plot area, the red data cursor and the same system of panning/zooming.

The new thing is the **Displayed series** dropdown menu, which allows the user to choose which data series will be displayed in given figure.

If there is a description page defined, clicking the name of arbitrary data series in the plot legend navigates to the *Outputs* section of that page.

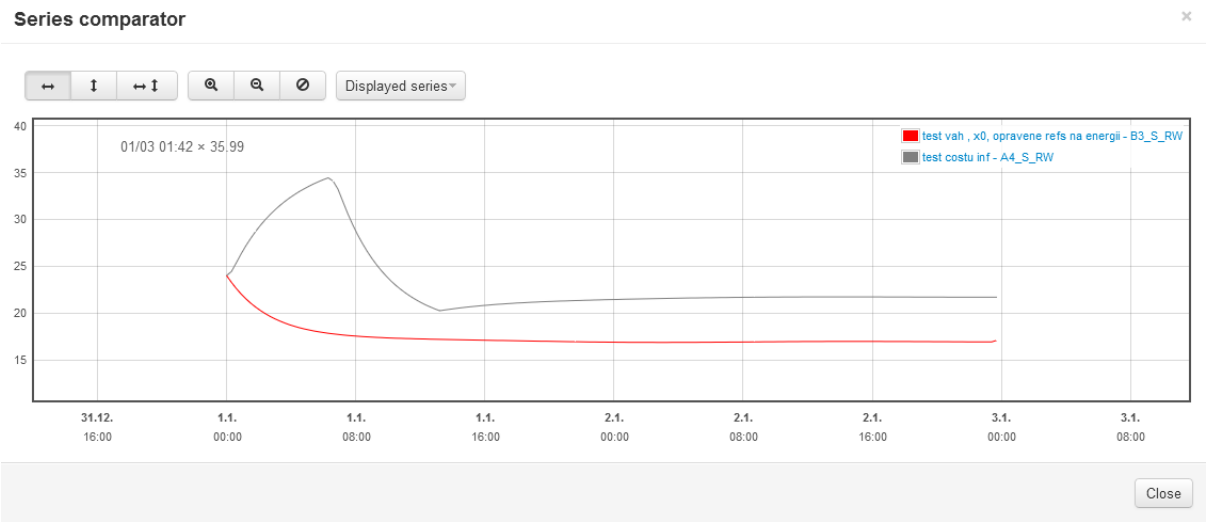


Figure 2.16: Series comparator

2.6.13 Django administration interface

Figure 2.17: Django administration interface – main page

The administration interface is accessible from the *User menu*, the interface is captured on picture 2.17.

The function of the interface is expectable and consistent. Clicking the label on the main page (specifically **Groups**, **Users**, **Generic problems**, **Object descriptions**) the user will get a listing of object of that kind present in the system. There are also

actions **Add** and **Change** with clear meaning. The interface does not allow to add simulations, because their structure is too complex to be expressed in the interface in some well arranged manner.

Django administration of simulations

As one example for all you can look over administration page of one simulation, see the picture 2.18. The meaning of all buttons is obvious, the meaning of editable items was briefly explained in section 2.6.7. Just to specify:

- **Owner** – Changes the user which is considered to be a creator of the simulation being edited.
- **Is public** – When checked, the choice causes the simulation along with its potential solution to be visible for anonymous (not-logged-in) users.
- **Is template** – Determines whether the simulation is treated as a working copy (unchecked) or as a template (checked).
- **Presentation** – Allows an administrator to choose between available presentations of the simulation form.
- **Name** - Allows editing the name of the simulation.
- **Descriptor** – Combobox determining which description will be used for given simulation. More on this below.
- **User description** – Allows a change of user description.
- **Viewer users** – Selects which users will see this simulation in their *Templates* listing (in case the simulation is a template) or in *My copies*/*My results* listing in case it is not.
- **Viewer groups** – Selects which user group will see the simulation. For all users in given groups applies the same as written for **Viewer users**.
- **Maximum time to wait for dequeuing** – Sets the time in seconds, after which the enqueued simulation will be aborted if no worker dequeues it.
- **Maximum time for solution** – Sets the time in seconds, in which the core dealing with the simulation must manage its solution. If it does not manage it, the task will be aborted.

Django administration of object descriptions

To be complete, this allows the administrator to relate the simulations with given descriptor. More on this in separate section below.

Django administration of users and groups

These modules are present in the interface by default. Refer to the Django manual for details.

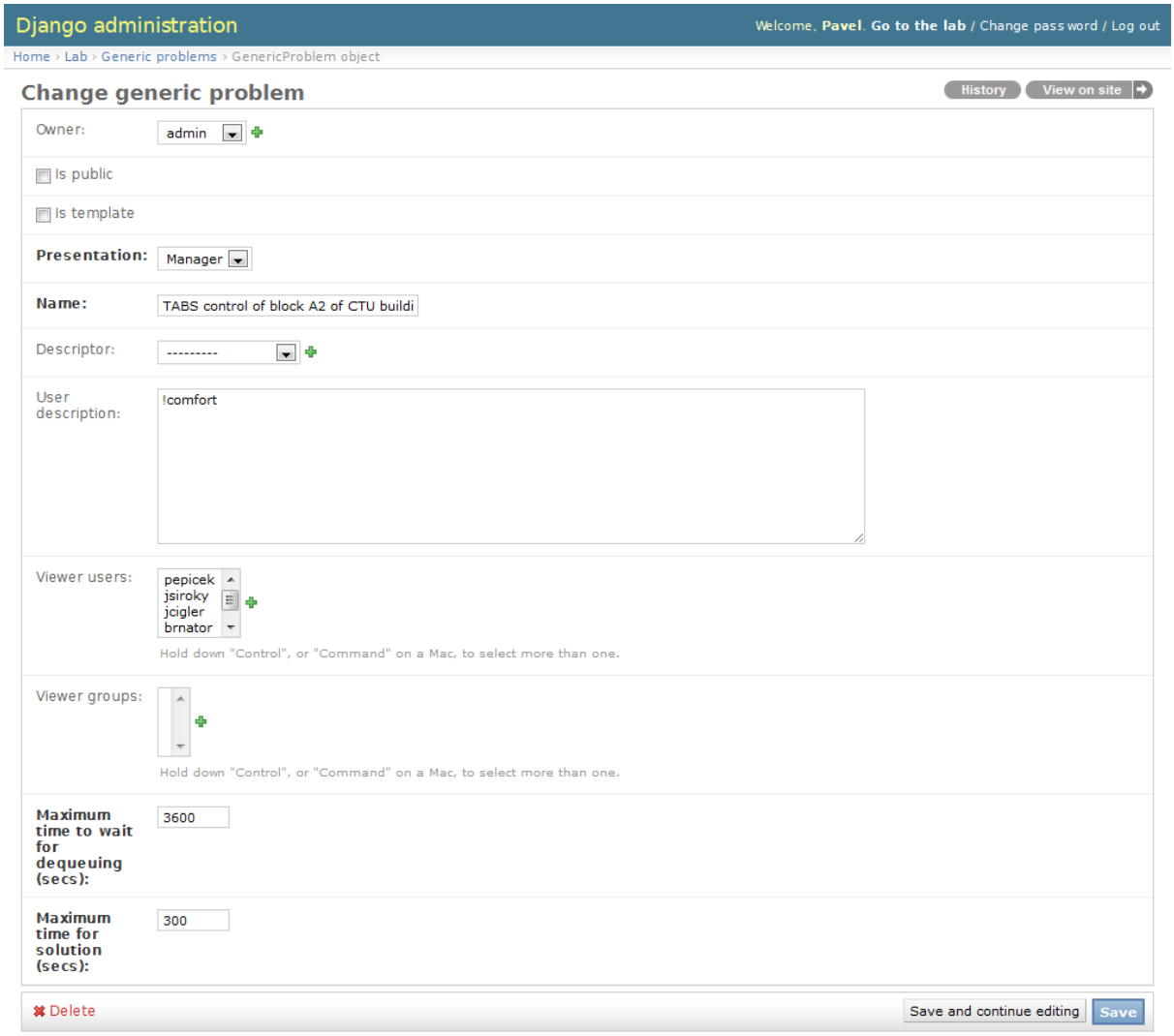


Figure 2.18: Django administration interface – editing simulation

2.7 Loading data into the application

This section describes the process of inserting new simulations and creating new data series in the repository. Actions, described in this section, cannot be done using the web interface. An administrator must have an access to the underlying database through the Django application console.

2.7.1 Loading simulations

For creating new simulations, the YAML files, describing simulation for on-line control are used. These instructions figure on the fact, that the system is cleaned from simulations as next-to-last step will overwrite the specifications on workers but the new ones. Updating the old definitions on workers is unfortunately not yet handled.

Assimilation of the data can be done in following steps:

1. In MATLAB, load YAML files, as would be done by on-line. This is done by command:

   ```
   spec = ReadYaml('main_file.yml',0,1);
   ```

   with `main_file.yml` being the root file of on-line implementation definitions.

2. Enter command

   ```
   WriteYaml('spec_working.yml', Spec)
   ```

   which writes the data just loaded into the new file `spec_working.yml`. Now all simulation definitions (imported and mixed in) are written in this one file.

3. Now it is time to decorate the file by the initial states and weight mappings. If adding of these is needed, refer to Sections 2.7.2 and 2.7.3.

4. There is a file in `buildinglab` folder of the application, called `admin_routines.py`, which contains helper functions to insert new simulations. Open the operating system console and navigate to the folder. In first rows of `admin_routines.py` is a line, beginning with `pth = '...`. Ensure, that the string, which follows, contain an absolute path to the root of the application (the folder, which contains the `buildinglab` folder).

5. Execute command `manage.py syncdb` (with appropriate changes of the command on Linux). This will start Django maintenance Python console.

6. In the console, issue command `execfile('admin_routines.py')`, which loads helper functions into the console namespace.

7. Load the specification file `spec_working.yml`, created in MATLAB by command:

   ```
   with open(r"spec_working.yml",'r') as f:
     specdict = yaml.load(f)
   ```

8. For given model-controller pair, which is to be inserted, launch command:

```
gensim = specAssimilator(specdict, 'controller_name', 'model_name')
```

   where `controller_name` and `model_name`, respectively, are names of the model and controller in the specification files. `gensim` variable now holds the instance of Django model `GenericSimulation` of the simulation just inserted.

9. Load appropriate definition of simulation outputs for plotting:

```
with open(r"some_plot_definition.yml",'r') as f:
  plotdef = yaml.load(f)
```

10. Enter command:

```
plotAssimilator(plotdef, gensim.concrete_problem_object)
```

    which associates given plotting metadata with the simulation. Repeat actions from step 8 to insert all model-controller pairs wanted.

11. After the insertion, execute:

```
specDictClean(specdict)
```

    which clears all specifics of the on-line run (data series, reference settings, etc.).

12. Save the cleaned structure by command:

```
with open(r"cleaned_for_matlab.yml",'w') as f:
  yaml.dump(specdict, f)
```

13. In MATLAB, load the file `cleaned_for_matlab.yml` using command:

```
spec = ReadYaml('main_file.yml',0,1,0,1)
```

    Please consider switches on the end of the command (it is different from the one in step 1). Especially the last one is important, because it disables the YAML importer form performing inheritance. If the switch is not present or is 0, inheritance will pollute your cleaned data by defaults from higher-level definition classes, which will issue no error, but will probably lead to strange simulation results.

14. Save `spec` variable as file `Spec01.mat`:

```
save('Spec01', 'spec')
```

15. Finally distribute the file `Spec01.mat` to the worker machines, into the folder `blab/scripts`, located in the root of worker SW equipment.

2.7.2 Adding the initial states to the definitions

There is a field added to the YAML definitions, added to the root of a selected model. The model section of YAML may then look like (unimportant fields omitted):

```
dejviceTempA1:
  ...
  BLinitialStates:
    fields: [A1_S_Room, A1_S_RW, A1_N_Room, A1_N_RW, A1_S_SW, A1_N_SW]
    states:
          -   name: 'Cooled down'
              value:
                  state: [ 19.5, 24, 19, 24]
                  initial: [ 19.5, 24, 19, 24, 26, 25.7]
          -   name: 'Overheated south'
              value:
                  initial: [ 23.5, 28, 21.5, 26, 35, 25.9]
          -   name: 'Overheated north'
              value:
                  initial: [ 20.5, 26, 22.5, 30, 27.8, 36.1]
          -   name: 'Overheated both circuits'
              value:
                  initial: [ 23.5, 28, 23.0, 26, 37.2, 38.7]
  ...
```

Values under `state` key will be used as initial measurements, supplied to the simulation backend as variables, named by the content of `fields`.

Values under `initial` will be used directly as a vector of initial state.

Each item of `states` list will be expressed as one item list in *Initial conditions* control in the web interface under name, determined by the content of `name`.

2.7.3 Adding weight mapping to the definitions

In each controller YAML specification, which should support the weight mapping for the *manager interface*, there is following dictionary defined (example for `MPCcontrollerB3`):

```
MPCcontrollerB3:
  ...
  BLweightMap:
      MAP1:
          B3_S_RoomCost:
            dstVec: [[1.0, 0.0]]
            src: HW_1
            srcVec: [[0.0, 100.0]]
          B3_S_HeatCost:
            dstVec: [[0.0, 1.0]]
            src: HW_1
            srcVec: [[0.0, 100.0]]
    BLhiWeights:
        HW_1:
            value: 50.0
            description: Overall weight - comfort vs. economy
  ...
```

In `BLhiWeights` dictionary, there are *Overall weights* defined, which will express themselves each as one slider. Currently there is always only one. The `value` field determines the initial value of the slider. Description is a string, which identifies the slider in the web interface.

The value from the *manager interface* slider is transmitted into MATLAB. It is always between 0 and 100. The value is transformed using linear interpolation with the XY grid created by `srcVec`, `dstVec` respectively. `src` field is the identification of the source slider from the `BLhiWeights` section. Resulting value will be used as a weight for variable with the name being the same as a name of the key the transformation is defined in.

To make things clear: In the example above, there will be one slider created, which will be labeled 'Overall weight – comfort vs. economy' and will have a default value 50. This slider will be identified as `HW1` in MATLAB. After the simulation is started, slider value 0 is transformed to 1 and stored as a weight of `B3_S_RoomCost`. If the slider is on value 100, the resulting value will be 0. Numbers inside this interval will be linearly interpolated. Value of `B3_S_HeatCost` is obtained by the same way, but the slope the slope of the interpolating function is opposite to the slope of the for `B3_S_RoomCost`.

2.7.4 Loading data into the repository

1. Run the Django maintenance console and load `admin_routines.py` as described in the previous instructions.

2. Some way load the data into the Python console workspace. There are many ways how to do it, it depends on the format the data is stored in. Before loading to the application database, the data must be formed to list of lists. Inner list must have exactly two items, first of them is time in milliseconds (UNIX time * 1000), second one is the value of the variable in that time. Example:

   ```
   data = [[1.0,2.0],[2.0,3.0],[3.0,-2.0]]
   ```

3. Load the data into the system:

   ```
   modrep.RepositoryItem.new(data, 'Name to identify the series')
   ```

   There is a routine, called `saveSomeData` in `admin_routines.py`, which creates simple sinusoid. Study its code for a basic idea about how to create and store the data series.

2.7.5 Description system

There can be a description associated to each simulation. The description is stored as a plain HTML file in some static folder of the application web server, accessible from the internet. The file self should make sense as a whole, because it can be displayed in the when user clicks the button with the '`i`' letter.

The same file is used as a source of concrete descriptions for setting blocks in simulation forms. See the grey boxes on the Picture 2.9.

There is a method `load` of jQuery library (more info in Section 3.7.1), allowing AJAX load of a file, content of which is parsed as HTML and used as a content of given DOM element. Nodes in the description HTML file are labelled using HTML class attributes, corresponding to the names of the adjustments blocks being described. `load` function is then used to locate the parts of the file into the appropriate places. There are many AJAX requests initiated, but all but the first one will be replied from the web browser cache.

The URL path to the file is stored in the `ObjectDescription` model along with path to the *resolver* Java Script file, which will be loaded before any description. The file provides the `resolveHelp(helpClass, helpIdent)` function, through which all requests for description are passed through, making it the extension point of mapping between described blocks and the description HTML file. To describe particular simulation, create appropriate HTML file, the `ObjectDescription` object and associate it to the simulation being described.

The resolver function is called for every described element with following attributes:

- `helpClass` – Cathegory of description. Can be one of following:
  - `'constraints'` – Description of some tab of the *Constraints* block.
  - `'costfunction'` – Description of some tab of the *Cost function* block.
  - `'disturbances'` – Description of some tab of the *Disturbances* block.
  - `'simulation-settings'` – Description of *Simulation settings* block for the engineer interface.
  - `'simulation-settings-manager'` – Description of *Simulation settings* block for the manager interface.
  - `'simulation-description'` – Short description of a simulation as a whole.
  - `'hiweight'` – Description of the *overall weight*.
- `helpIdent` – specifier of the concrete object being described.

Resolver matches the `helpClass` and `helpIdent` string pair to the selector for mentioned jQuery `load` function, which it yields as a return value. See the jQuery documentation for details.

There was an issue observed: When the path to the HTML description is stored as a path to the directory, where an `index.html` file is stored and the path does not with a slash, server will return a non-permanent redirection, causing the browser to reload the same content of the description file many times (debugged with the Firebug extension of the Firefox web browser). It is recommended to check the initiated connections using the Java Script debugger, to eliminate possible waste of server resources.

Chapter 3

Developer point of view

3.1 Architectural overview

The heart of software is an application written in Django – see section 3.8.1 (web framework for Python programming language – see section 3.4). Data persistence is backed by PostgreSQL relational database – section 3.10.

The application distributes computations on several cores (at the moment running on MATLAB). Cores poll the database for tasks using HTTP protocol and saves results there as computation finishes.

3.2 Top level component interconnections

The components mainly communicate over HTTP in the current configuration. However the system uses well-established and proven technologies, which can easily scale.

The current configuration is in the picture 3.1. All participants of the system (workers, web browsers) communicate with the application through HTTP, using only one web server. The web application connects to the database running on the same machine via the proprietary protocol of the database.

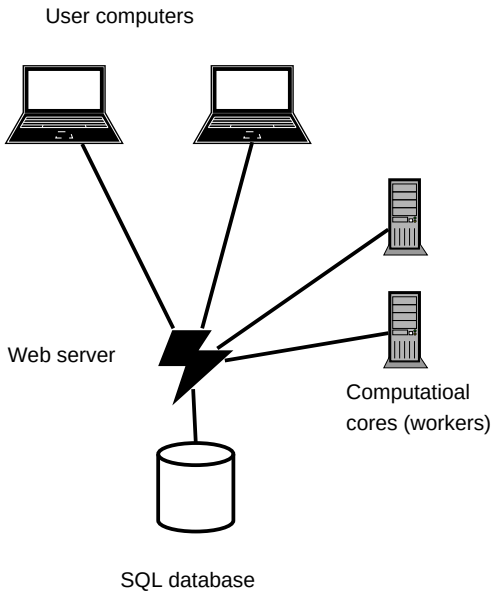


Figure 3.1: Current system configuration

It is possible to operate the system in the form, proposed in Figure 3.2. The design figures on running lightweight web server on each worker machine, and so creates more potential extension points for e.g. doing some preprocessing in Python code, but not wasting the resources of the primary web server.

The lightweight web server can be one of many available, which allows the use of WSGI [20], for example Fapws [6].

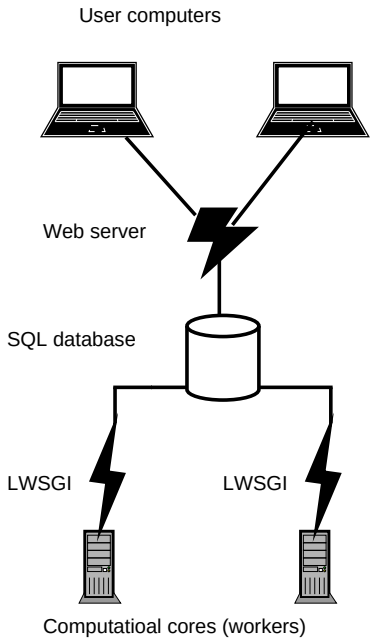


Figure 3.2: Full system configuration. LWSGI stands for Light Web Server Gateway Interface.

3.3 Software packages used in the application

The application uses mainly following software packages/products:

- Python 2.7.2 – main programming language of the application
- Django 1.3.1
- PostgreSQL 9.1.7
- Numpy 1.4.1 – for data series cut-out, resampling and time shifting
- Apache HTTP Server 2.2
- MATLAB R2011b
- SnakeYAML 1.9
- Java Virtual Machine 1.6.0-17 (part of MATLAB)
- GNU screen – for ability to keep workers running with detached terminal

3.4 Python programming language

This section could easily become a chapter, even a book. This section will mainly discuss the language typing in short, because it was the most noticeable aspect of the language throughout the project.

Just to be complete: Python is feature rich language, which allows both rapid prototyping and writing complex applications. It is an interpreted language and is easily readable by humans.

During the research, there was a lot of time spared by searching through the web, why there are people who dislike it and exalt PHP above, when we talk specifically about the web development. No satisfactory reasons were found, maybe the one that the Python language specification changes faster than it would be appropriate, resulting in inter-version incompatibilities.

This cannot be judged without a try to rewrite any application for another Python version, but one can dare to claim that in the matter of pure Python, this could be even automated process. Problems come when there are some native extensions, which need to be rewritten and compiled again. But web developer for common middle-scale sites probably will not write native extensions, only may have problems such that the database backend is not yet compiled for the newest python version, so cannot be used.

Hard to say, hopefully it is not such a big problem. [1]

[1] To be honest, the framework used in this work – Django – is not yet compatible with the last version of Python, although the version is already out for a long time, so it is somewhat problematic, especially when there is a lot of advanced language construct used – which in Django sure is.

As a dynamically typed language, people who came from the world of Java may initially dislike Python, because Java is in principle strict in typing.

One possible reason of Java popularity can be its type safety and language strength in the sense that a language tool (IDE, programming editor) can track nearly every variable throughout the code, thus for instance automatic method renaming can be performed and it can be sure (at least if the reflection was not used at this point) that the language will allow proper tracking of the method being renamed or refactored. Java classes have all precisely defined interface, which is one of its biggest strengths.

In Python, this is hardly possible, because there is no certainty that method of the particular name will be on the same place next time. Application can delete the instance variable or method on the fly and it is gone without generally no chance to know about whether it happens at the development time. Python has no interfaces at all and although they can be implemented as a kind of an extension, this would be probably called as 'non Pythonic' approach. The type system here is called *duck typing*, its principle says roughly 'If you see an animal, which quack like a duck and swims like a duck, then you can say it is a duck.' [26].

The fact that a programmer can define a method whenever wants and is not forced to design against an interface has an implication of faster and cheaper development than in Java. But it is not so simple. Both languages (typing systems) need a developer to have some design skills.

In Java, application is designed against an interface. Developer will struggle with its strictness and simplicity, because he or she will have to abstract a real world, which is not so simple, in Java terms and constructs.

In Python, software is designed against a contract. This means struggling with the exact opposite thing. It allows to do maybe too much, which can recoil on the developer in the means of code mess and difficult refactoring, because it is easy to break the contract even without knowing about it.

Both languages have their pros and cons, every one suit to some sort of problems. Python is more feature rich and more flexible. It is a better language to learn something with, because there is no need to deal with very constrained design possibilities and a beginner can simply concentrate on technology he or she wants to master.

3.5 Brief introduction of YAML format

YAML [22] is according to its official site 'a human friendly data serialization standard for all programming languages'.

In its simple form, it is very similar to the Python or Javascript format of dictionaries and lists definition. In the full form, it can be annotated by metadata to determine, which class was serialized. But full-featured YAML was not used throughout this work, except for storing date and time records.

The format is well established and human-readable, which suits it particularly well for academical usage, where is often needed to change the raw data by hand. In addition, there are parsers for many languages

Its weakness can be storing some larger datasets, especially large number of classes, annotated by its type. Parsing is then potentially slow and annotation data overhead grows.

The format is a primary format for data storage in original MPC scripts.

An example of YAML file (Taken from [22]):

```
---
Time: 2001-11-23 15:02:31 -5
User: ed
Warning:
  A slightly different error
  message.
---
Date: 2001-11-23 15:03:17 -5
User: ed
Fatal:
  Unknown variable "bar"
Stack:
  - file: TopClass.py
    line: 23
    code: |
      x = MoreObject("345\n")
  - file: MoreClass.py
    line: 58
    code: |-
      foo = bar
```

3.6 YAML interface for MATLAB

At the beginning of the project, there was need to purify a way YAML files were read and written by the MPC controller to get rid of some bugs and make it more transparent.

The implementation used and still uses SnakeYAML [17] . This library is written in Java and basically transforms YAML text file into structure of Java lists and dictionaries, filled with appropriate data types (Java strings, doubles, integers, date objects). It can do lot more, but for the project, simplicity was of a strong importance.

So the goal was to transform this Java data structure to MATLAB one. It was not so easy, because there is no direct mapping between list-dictionary-primitive structure and all needed MATLAB types.

MATLAB has two kinds of matrices in base – common matrices (have all elements of the same type) and cells (can store arbitrary data types). Matrices can have more dimensions, cell matrices can contain another cell matrices and common matrices.

Moreover, there are MATLAB structures (better speaking maps), which have string keys and each value can be of arbitrary type mentioned or another structure.

We had to restrict a set of expressible data structures with the needs of our specific application taken into account. For the system model, there are matrices of maximal order of two and data should look well arranged in YAML – column vectors ought to be

column and similarly for row vectors.

Thus when there is possibility to concatenate given list of lists to a matrix (same data type, same count of elements in leaf lists), common matrix is created. This process works up to the depth of two.

For example:

```
A:
  - [7,8,9]
  - [0,3,2]
B:
  - [4]
  - [5]
C:
  - [1,2,3]
```

will create structure with one key `A` storing 2-to-3 matrix, key `B` storing two-element column vector and `C` storing three-element row vector.

If the data types are incompatible (Date and number in the same list) or lengths of inner lists are different, reader issues a cell matrix.

YAML writer was written to work the opposite way – data written from MATLAB to YAML and read back should be the same as written.

There was also a requirement for the reader to support *imports* and *mixins*.

Both features mentioned are the same in principle. *Mixin* is a merge of two dictionaries, which are concatenated to one new dictionary, with *child* dictionary keys overwriting the *parent* ones when they have a same name.

So in general, when there is a key named `parent` in the YAML dictionary, the dictionary, which contains it is considered to be a *parent*, the rest of the data is looked up for another key of the name specified by the value of `parent` field and its value is used as a *child*.

When there is an `import` key, the behaviour is almost the same with the difference that the content of the file, with name contained in the `import` value is considered to be a *child*.

See YAMLMatlab page [23] for further details.

3.7 Web browser part of the application

Web pages evolved a lot during past years. They are no longer only HTML documents, rendered from static files. The trend is to make web pages to make user feels like he or she works with the real desktop application. This involves client-side scripting to be used intensively.

Today, the most widespread language to be run in a web browser is Java Script. It is simple language, similar to Java in syntax, but has its own manners. Java Script is more and more powerful, which allows the developer to write really sophisticated applications like word processors and spreadsheet processors and run them in the browser.

Java Script itself is quite lightweight and not feature rich, hence many extensions were

written to make routine tasks easier and less error-prone and to span differences between various browsers.

Amongst others, the most widely known extensions are jQuery and MooTools, both a little similar in purpose, but with slightly different philosophy.

3.7.1 jQuery

This Java Script extension was chosen for the application, because is probably the most widely known and looking to its manual and tutorials signalled that this is the right choice. Moreover the extension is used by Bootstrap library for its plugins interactivity.

It has small code footprint and is light as a basic package. But even the basic one comes with really helpful utilities:

- Document object model (DOM) manipulation – Offers methods, which can very simply do operations with the HTML document tree like add, delete, move, adding and removing CSS classes in a cross-browser compatible way. It abstracts out lots of browsers quirks and truly simplified the application development.

  These features were used throughout the application, for example for hiding and showing the arrow, indicating tasks in the queue.

- Advanced event management – jQuery simplifies the work with events, creating user defined events and creating event handlers. In the application, there is lot of *event bubbling* used, when events traverses the DOM tree up (*bubbles*) and triggers event handlers on its way, registered for type of that event. It is possible to stop this propagation and emit another event for instance. Or only prevent the event to trigger its default behaviour (for example link navigation or form submission).

  Instead of hooking each element, where something could happen, handler can be attached to the common node of the DOM tree and captured events can be processed on this (one) place.

  Events are used almost everywhere in the application where some button is possible to be clicked. There was a strong effort to use event bubbling, to optimize number of handler bindings and thereupon optimizing the application responsiveness.

- Active Java Script And XML (AJAX) – The term AJAX is nowadays used more likely for any connection initiated from the browser, which does not come from any browser plug in (e.g. Flash or Java applet) and does not involve any page reload or navigation.

  jQuery again encapsulates browser differences in this technology and offers methods that allows content to be loaded into some DOM node or to load JSON content, both things in one or two lines of code.

  AJAX transfer is used for dynamic loading of description blocks in the simulation form and on polled pages. There is no page automatically reloaded. Instead only part of the page is reloaded, which means better user experience (page and browser

suffers with almost no flickering and menus are operable whole time, no matter how many times the content is reloaded).

3.7.2 Bootstrap

This is a library, giving the application its appearance [4]. Basically it is de-facto one clever CSS file, with possibility to be extended with some jQuery interactive components.

The reason it was chosen for the application is that it is good looking, very easy to use and lightweight. It rids the developer of a necessity of having deep knowledge of CSS and various browser differences or bugs, so he or she can concentrate on the application functionality itself.

The library is good for quick starts, however it is said to be non stylish and not much extensible inside its code. Maybe it is a necessary compromise, because for example its Java Script addon files are really minimalistic.

3.7.3 Flot and graphs in the application in general

Flot is a tool for rendering graphs using Java Script in the browser [7]. It is very feature-rich and no such a good alternative was found on the internet. It has outstanding documentation including examples and fairly understandable API.

Its functionality was widen a bit to be able to reload displayed data on the fly as the plot area is resized or panned for *Data cut-out picker* (see section 2.6.10).

In the picker, whenever user changes zoom or panning and does no such action for next 300ms, an AJAX request is sent for new data. The request includes new time starting point, new time end point and size of a plot area in pixels.

Server then resamples the data to return approximately the number of data points, which is equal to the number of the pixels, which saves bandwith.

When the user requests a view, which is zoomed out sufficiently to call for every n-th data point from the database, decimation will take place already on the database level (otherwise every small movement of the graph could result in transmitting of all data form the database to the web server, which is 1.2MB now).

Decimation in PostgreSQL is achieved by first ordering the data by its time and then selecting each n-th row using function computing modulo n. It needs a row number to be determined, which functionality is unfortunately not a part of SQL standard. In the application, PostgreSQL *window function* `row_number()` [14] is used to determine the number.

3.8 Web development – using a framework

This section is only a brief summary. The theme could be laid out over many thick books.

Web development is probably the mainstream development activity done on the internet of today. This is maybe the biggest reason of why many programmers tend to make their daily routine more pleasant. As a side effect, there were several techniques, methodologies and concept established to reduce code repetition, increase component decoupling, increase decoupling between data, business layer and html presentation. Tools for development considering such stuff and even more are concentrated into packages so called *frameworks*.

Frameworks not only provide 'physical' codebase for projects, but also provide 'philosophical' knowledge base, e.g. how to organize the code, how to organize the data, how the validation and request routing should be made, which is of the same importance as the code library. They frequently allows the user to apply the *Don't-Repeat-Yourself (DRY)* principle more easily, which means in consequence less copy-paste operations and less bugs.

There are several framework types, diversified by several criteria. Most dominant and spoken are perhaps *Model-View-Controller (MVC)* frameworks, named by three main components, which together constitute the application.

Frameworks can deal with sessions, authentication, even creating PDFs but they could (or should) contain these tools in general:

- **Model layer** – This is where the metadata is defined, including relationships between the data and probably with the validation rules. The model is alpha and omega of the MVC application.

  If a developer define it well and used framework is 'well behaved', then any new operation with the data under that model is very likely to be implemented quite fast, because the model logic will handle many important actions, sometimes simple, sometimes complicated ones, often tasks, which are repeated on many places without a framework and hence are very error-prone.

- **Object-relational mapper (ORM)** – The model is often described in an object-oriented way, which is quite in a conflict with widely used relational database technology. We do not want to claim that ORM must be used, only that using of it could make a developer's life easier. Of course, ORM must be well designed, otherwise it could turn itself from a rescuer to a nightmare.

  The ORM basically maps every fetched row from the database to one mapped object instance and vice versa. But it can sometimes map more instances per row or more rows per instance too.

  All queries are possible to be coded by hand in raw SQL, but this is said to be very error-prone, often dangerous, last but not least a tedious work. A programmer must properly handle quotation, carefully test all queries to be sure he or she has not forgotten any punctuation somewhere. In raw SQL, there is no kind of SQL-builder support.

- **SQL-builder** – This should be an implicit part of most of the ORMs. It is the Swiss knife for querying against the Model. Specifically, imagine the developer knows that he or she would like to query against table A, so in SQL he or she would start

```
SELECT * FROM A
```

Then a program flow passes through some condition, where is decided that there is a need to sort the rows by, say, `day` column, so appropriate `ORDER BY` clause is added:

```
SELECT * FROM A ORDER BY day
```

Now the code passed to the place where was decided that the rows should be filtered to contain only those with `salary` bigger than 1000. How to do that? There are basically three approaches, maybe more:

- The last query can be some way split then inserted the `WHERE` clause to obtain

  ```
  SELECT * FROM A WHERE salary > 1000 ORDER BY day
  ```

- Brand new SQL statement can be made for every possible branch. But imagine how many branches there can be, how large part of them will be identical and the work to do when there is a need to change this common part later.
- A programmer can use some SQL builder, where he or she could solve the example easily with code similar to:

  ```
  query = A.objects
  ...
  query = query.order_by('day')
  ...
  query = query.filter(salary__gt = 1000)
  ...
  # Another actions with query...
  ```

  In principle, the builder will incrementally create the SQL tree and then transform it to SQL string just before the database is to be hit.

  The ORM will automatically instantiate objects of the Model including their relationships. Ideally the builder plus ORM should constitute a transparent system without user having to know that he or she actually uses a relational database.

- **Well established controller architecture** – This is the mechanism, which maps concrete URL to a method, which will handle the request, call appropriate methods of model and renders the right response.

- **Form management** – Gathering informations from users is also one of the crucial things. Framework handles the form with everything it involves. It creates appropriate fields and grabs data from the HTTP request, dealing with decoding them from URL or POST data. It will validate data the user entered to check for its correct data types, for various kinds of attacks and so on.

  Frameworks can also go far that they generate the form automatically using informations from the Model. Coding forms in HTML and handling them manually is really slutifying job and frameworks can make it fun. At least partially.

- **The templating engine** – Applies the DRY principle on HTML. Allows to establish HTML inheritance and to reuse parts of the code. As a result, HTML will simplify with a better chance for bugs to be fixed and to make changes.

This can be said for middle to mega frameworks. There are also so called *microframeworks*, which has minimum functionality, leaving vast free space for developer's creativity to use only pure programming language or to use any libraries.

3.8.1 Django

Parts of a web framework were partly enumerated in the previous section, which was done partly with Django in mind.

For the application, it would be best to emphasize following aspects of the framework:

- **Model** – Model is an integral part of Django and also probably the most useful and beneficial one. It is an embodiment of Django datacentric philosophy and does lots of things under the hood. All data entities are defined there including all their attributes and associations using declarative style, which is in accordance with *write less, do more* principle.

  For example declaring a field to be a float field is one line of code for the application developer, but model library of Django sets up validation for the data type, is able to emit form field for this data field, generates SQL for creation of table for the class, which includes this field and so on. Everything tries to do as transparently as possible.

  ORM of Django is simple to use, but lacks possibility of performing some more complicated tasks, which often leads to suboptimal approaches with complex queries.

- **Templates** – Django templating system tallies with the general description above. It is maybe too feature-less, which was probably an intention (templates are often written by non-programmers), but during the application development, there were several features really missed, like more advanced conditions or very constrained possibilities of calling python methods from the template.

- **Forms** – The framework is able to generate forms based on the model, ideally only needing some more declarative description of how exactly to do that.

- **Authentication** – Seamlessly adds an information about logged user into the `request` object, which is passed into each view method. Also provides autogenerated form for log in and many other useful tools.

3.9 MATLAB

MATLAB is well known and well-established computational system. It is not only a clever calculator, it is de-facto programming language.

The language have not changed radically since its beginning so that it looks quite ancient in some aspects. Good for compatibility, but not for people. It is very outstanding in many kinds of computations, especially the matrix ones, has very wide area of libraries and toolboxes, but lags behind others in matter of 'modern' features like pointers/references, and is quite slow in many cases.

3.9.1 How to call MATLAB from outside

The fact is that while there is a variety of ways to call third-party libraries from MATLAB, there is also a lack of official (and comfortable) ways how do so reversely, at least without some additional toolbox.

MATLAB has the Java Virtual Machine built-in as its core component and the Java language is well accessible, including most of third-party libraries. But again, there is no clear and official way of calling MATLAB from Java.

There are possibilities how to bypass this shortage. MATLAB can be launched with the statement wanted to evaluate entering it to the command line, but this is very slow (one MATLAB start per one statement execution). Periodical file read and write operations are also possible, but it is slow as well and – not least – ugly.

Moreover there is no easy mechanism how to transfer data between MATLAB and the outside world (even Java). Matrix can be passed to some Java function, also some string, but starting from structures and cell arrays, developer is out of luck and needs to specify 'protocol' saying how to marshal and unmarshal every data structure which is somewhat complex.

There is an undocumented feature, the Java-Matlab-Interface (JMI) [8], which is used by many people to achieve the MATLAB call. There are some third-party libraries, which try to encapsulate the solution of this problem, for example `matlabcontrol` [9].

The final decision is not to take somebody else's solution. Details will be cleared later in section 3.12.6.

3.10 Data storage

There came out some different points of view, when the project was consulted with other people. Possibilities were generally these:

- *Use text files, use YAML files, use CSV files* – Filesystem is very fast, but using it for BuildingLAB data storage would be very likely complicated and error-prone.

  The application was from the beginning heavily experimental in the sense that there was quite unclear what *exactly* it should do. The approach 'Take a bunch of files, load them all, parse them all, take value here, take value there, compute something, save another file...' is suitable for one-shot scripts. But our case, since it has begun, is something that has some not-entirely-trivial state, there will be some kind of user authentication, structured data, possibly large data sets and so.

There will be many relations between data anyway and manual handling of these not well defined references, which are in addition very likely to change is very hard to implement in filesystem, even harder to debug.

A schema, which could handle this, was to be designed with a lot of effort, but it was cut off because of the decision that some technology, which is established for handling the data needed is a better and much more flexible choice.

- *Use some kind of non-relational database* – Nowadays, these databases compete with the relational ones. As their name says, they do not have relations, which was recognized in the project design so far though. There is a possibility to mix relational and non-relational databases together, but this would perhaps need lots of time to manage for the first time and lots of skills to fine-tune and debug. On top of that, more servers would be needed to install and administer. We concentrated especially on *MongoDB* [10] during the initial research. Other possibilities can be found at [28], where the systems are also compared. Non-relational databases are extraordinary technology, and certainly will be considered next time, but finally the idea of using them was rejected for the application.

- *Use relational database* – The purity of relational databases and the fact that they are on the market for many years make them to be used very often even in new projects which would be even beter suited with another kind of storage. PostgreSQL [13] and MySQL [11] are (amongst others) an outstanding technology, both of these incredibly available for free.

  The final decision is to use the relational database only. We have been already familiar with PostgreSQL an SQL at the time the project started and one more for the relational database: the framework chosen – Django – was designed with the idea that it will be used with such a database and the idea is grown throughout the whole framework.

  There are some packages for Django, which introduce other kinds of database. Specifically for MongoDB, there is a project Django MongoDB Engine [5], which according to its documentation does quite a nice job, nevertheless it have not convinced us to use it.

  This is a final choice for the application storage, because we know the technology, we are quite used to think its way and it can in fact handle all needs of the application, to specify some: storing the application state, storing simulations, storing results, task queue, data repository.

3.11 What happens after clicking the Compute button

For a reader to become familiar with the core of the system, it is sketched, what happens with the simulation form, when the user clicks the **Compute** button.

1. At first, the button behaves as the **Save**. This involves data validation (data types, numeric value limits), then persisting of the simulation data.

2. New `QueueItem` object is created, which points to the simulation object using generic relation. This means that object is now enqueued and waits for worker to take it.

3. Some worker (Java poller running in MATLAB) with the name matching task aim pattern reports its *idle* state during some poll sending appropriate HTTP request, which dequeues the task and returns the task primary key as a response. This is actually almost the whole function of the poller, which then polls with *busy* status notification.

   Dequeuing also means that there is an association between `Equip` object and the dequeued item, which serves for the purpose of determining which worker is processing the task.

   When worker polls with the *busy* state, it serves et first to inform the system that worker is still alive. Every *busy* poll hit can also dequeue item, which is marked as *control*. At the moment, control messages are used only to abort computations. When the abort item is dequeued by poller, it performs JMI call causing currently running MATLAB script to interrupt as the user hits `Ctrl+C` and then starts polling with the *idle* status.

   Because an *abort* request is just another item of the queue, all control items overtake other items in the task queue.

4. MATLAB script is called, which uses `urlread` to download the assignment from the server, using supplied primary key. On the server, the data structure of simulation is recursively traversed, which results in a simulation assignment. The assignment is serialized as YAML data and returned as a response.

5. The script looks up the assignment for information about specific script which should be executed and executes it.

Now follow actions specific for the current implementation of MPC. The script flow is explained in section 3.12.7.

3.12 Application components

3.12.1 Data repository

Simulations can be feed with either constant or variable data. In the case of the variable data, we need some flexible source of it. In current MPC scripts implementation, the data are stored just another YAML file. This is quite useful for short online data series, but generally not sufficiently flexible. It has mainly these drawbacks:

- Current implementation of YAML file reading is disgustingly slow. It is not a fault of the format self, but of the implementation of libraries used to read it, mainly those written in MATLAB. The MATLAB code is highly recursive and YAML structures could be deep. Unfortunately MATLAB does not support references, so the recursion means that the data structures are copied over and over again. The read takes time, which is equal or even longer than the actual problem solution. This fact is causing failures in the online implementation, but users working with the web application are usually annoyed when their request is fulfilled in tens of seconds, not speaking about several minutes, which the solution of MPC problem usually takes. The effort is to shrink this time to be as short as possible.
- The YAML format has quite a space overhead if used for storing floating point numbers. It is even worse in storing information about date and time. In current implementation, there is by guess more than half space consumed by useless time metadata.

The repository holds the data, which are used to feed simulations by anything distinct from a constant value. The repository is finally implemented as s single table in a relational database, holding time-value pairs and having foreign key to teh table containing name of each data series.

3.12.2 Output series objects

Results of a simulation are stored into the database textfield as CSV data. There is `ResultItemSeries` oject for each data series of each simulation, which is prepared with the data textfield empty as a template, which is an information about which data the application wants from the computation script after it finishes. When the solution is ready after the computation, appropriate mappings of `ResultItemSeries` are updated, saving the data. The object also stores an information about the series name to be displayed in resulting graph legend and color used to plot the series.

There is also object named `ResultItemSeriesGroup`, which groups together series where displaying of them in one figure makes sense. The object holds name of the group to be displayed as a title of resulting figure.

3.12.3 Task queue

The queue self is implemented as one database table. The key moment is how the queued content is dequeued, because this includes select and update in a non-standard composition and should be done atomically.

In pure PostgreSQL, there can be used its extension of the SQL language. One dequeuing shot would then look like this (simplified):

```
UPDATE queue
  SET status=1
  WHERE
    id=(SELECT id
```

```
      FROM queue
      WHERE status=0
      ORDER BY id ASC
      LIMIT 1) AND
    status=0
  RETURNING *;
```

Every row is one enqueued item, which can have status 0 (enqueued) and 1 (dequeued). The inner `SELECT` orders rows by their automatically generated primary key (which is increasing sequence at least in PostgreSQL) and in efffect returns id of item which has not been dequeued yet and has lowest `id`. Outer `UPDATE` takes the `id` returned and marks the row as dequeued, changing its `status` to 1. Whenever there is an inner `SELECT`, the entire query may not be longer atomic as a whole. So we added yet another check of `status` field to ensure that the row was not dequeued by another process just between the end of the `SELECT` and the beginning of the `UPDATE`.

Unfortunately, `RETURNING` clause is not part of SQL standard and to make the application to be potentially compatible with other databases, finally was used similar double-checked solution (simplified):

```
UPDATE queue
  SET status=1, workerlock=%(wlock)d
  WHERE
    id=(SELECT id
      FROM queue
      WHERE status=0
      ORDER BY id ASC
      LIMIT 1) AND
    status=0;
SELECT * FROM queue
  WHERE workerlock=%(wlock)d
```

and then

```
UPDATE queue SET workerlock=NULL WHERE workerlock=%(wlock)d
```

`%(wlock)d` is Python syntax and means that this string will be replaced by variable `wlock`. This variable is a random number from large interval, which a dequeuing process will use to actually mark the queue item for later selecting its content. The `workerlock` has set a `UNIQUE` constraint to avoid collision. If the random number would be the same as the one already in the database, the `UPDATE` will fail and the item will be dequeued next time. The time when `workerlock` is not set to NULL is so short and the interval from which the random number is chosen is so large that probability of collision is very low.

There is a possibility of aiming a task to particular worker using pattern matching against its name. Dequeuing SQL query includes `LIKE` clause against an expression saved as a part of `QueueItem` object. The pattern field implicitly contains '%', meaning that anybody can dequeue the task. But for example aborting a task employs this technique to abort only the task chosen.

The mechanism is also good for debugging. There is a setting in Django configuration file introduced, which allows the administrator to set whether user with particular name, when logged, will automatically aim his or her tasks to particular worker.

Why (not) to do this in a relational database

However a relational database seems to be a best suitable tool to implement the queue (And it in principle may be), in practice, relational databases can be fast at `INSERT`, can be fast at `DELETE`, but probably will not be fast at both. If the application was large-scale, there would be problems with responsiveness. Opinions like this can be found in many articles. In one article for all, in [37] is said that any 'ephemeral data' should not go into a relational database. There are specialized key-value storages, log systems and particularly messaging queue systems, which will serve way better. The article is a bit too strict saying that even session data does not belong to the database, although doing this is a very common habit.

3.12.4 Generic simulation

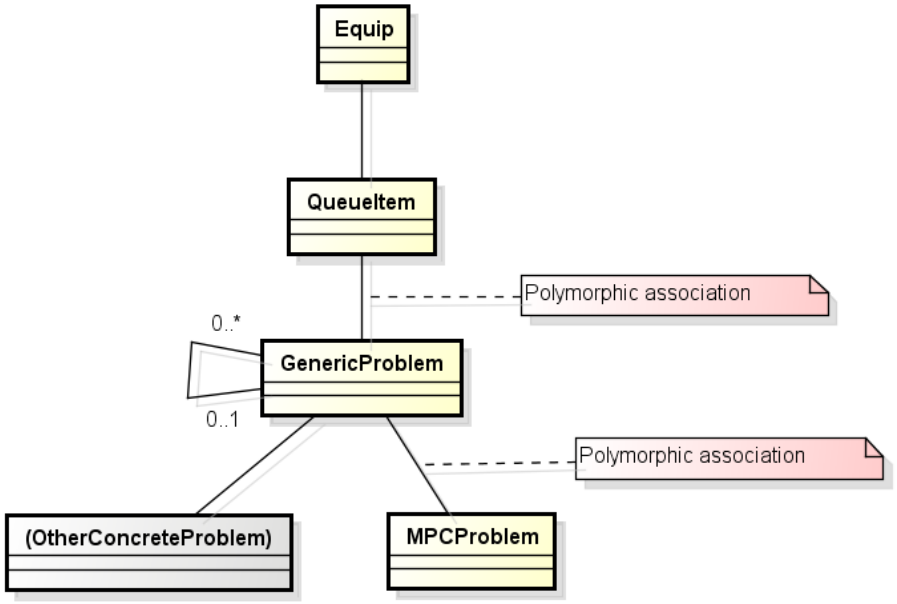


Figure 3.3: Polymorphic associations in the application. All associations are one-to-one.

This is de-facto a core of the application, so a simplified class diagram, representing the relationships between parts of the application and a parental relationship is seen in the picture 3.3.

During the development of the application, there was an exertion to think about it as being extensible, to look at it as a generic simulation platform. Moreover it was interesting to see, how the ORM works and how it will perform. So the `GenericProblem` object was established, which is base for all simulations, holding the data which is common for them, trying to loose-couple the concrete simulation object from the task queue and other parts of the system which it has nothing to do with.

The intention was to achieve such an architecture that as someone in future decide that he or she would like to found a fuzzy or another regulator or completely different simulation in a system, this implementation will not be overly painful.

Django has a built-in module `ContentTypes` which can provide such functionality. It abstracts *polymorphic relation* using third table, where the name of a targeted table is stored. At first sight the feature is very useful, but is exactly the one of the examples of constructs not suiting for the relational databases, which is maybe one of the reasons that the ORM facilities are even more restricted for polymorphic relations than for normal ones.

3.12.5 MPC simulation

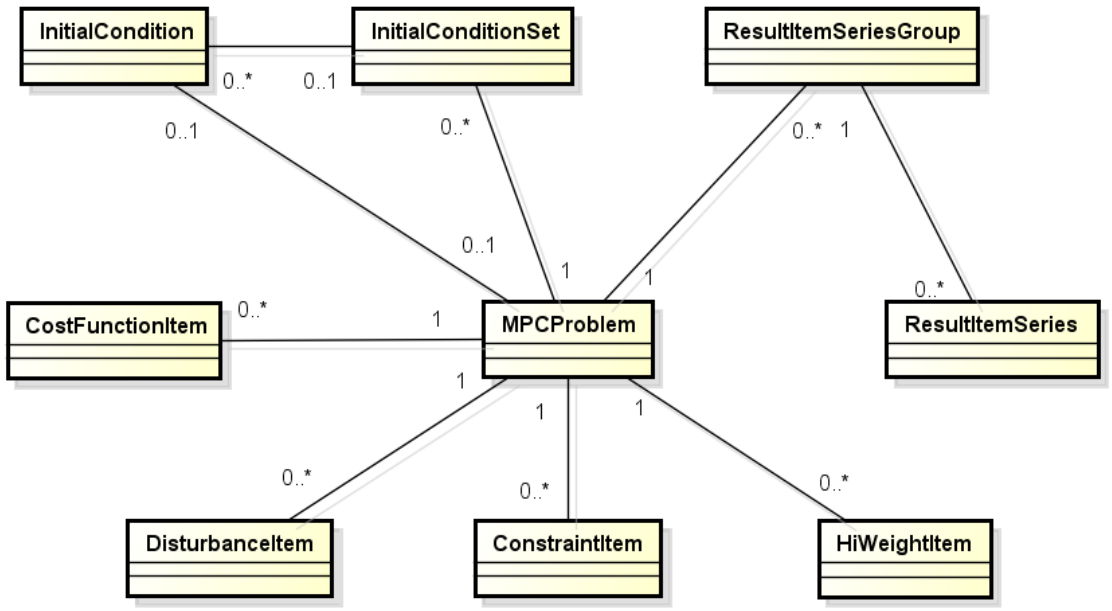


Figure 3.4: Class diagram of a `mpcproblem` module

This is a structure of classes, storing data about the concrete simulation. Their purpose is following:

- `MPCProblem` – root of the concrete simulation. Holds some general informations like prediction horizon length, model and controller name and script name to be launched for computation.
- `ResultItemSeriesGroup` – The object, grouping somewhat related data series together.
- `ResultItemSeries` – Output of the simulation, where the data is stored in a textfield (one series per object) as a CSV.
- `HiWeightItem` – Overall weight for the simulation.

- `ConstraintItem` – Object, reflecting the *Constraints* block of the engineer simulation form.
- `DisturbanceItem` – Represents the *Disturbances* block of the simulation form.
- `CostFunctionItem` – Represents the *Cost function* block of the simulation form.
- `InitialCondition` – Holds information about one possible setting of *Initial condition*. Selection of the state is indicated by existence of relation between this object and `MPCProblem`.
- `IitialConditionSet` – Object, associating the `MPCProblem` with all its possible *Initial states*.

3.12.6 MATLAB poller

Although recent versions of MATLAB have some operations implicitly paralelized, there is no core support for threads in MATLAB language self. There is Paralel Computing Toolbox, which could do the job, but it costs something and it is too strong tool for the purpose. This imperfection can be part way eliminated using threads of built-in JVM. The feature is not omnipotent. There is still only one thread of MATLAB interpreter, but the Java thread may do some non-computational work, like to communicate, which was used in the application.

There is a small class written in Java, which is launched in MATLAB and polls the message queue every 5 seconds. The poller is as small and simple as possible, hence minimizing needs of debugging in two environments (application and MATLAB side).

The communication handle was finally designed as a HTTP channel. The reason was mainly the fact that HTTP is old but yet widely used. It is fast and libraries implementing it mainly create some kind of abstraction and encapsulation above the TCP/IP layer, making the development easier. MATLAB has a routine for performing either GET and POST requests in its base libraries. Java also has this functionality built in. Moreover if the communication will be maintained using HTTP, there is no need to design any server side for MATLAB workers. They can directly call the web server with peer written in the same way as the application. Workers are in fact behaving as automated web browsers.

3.12.7 The MATLAB glue

The title of this section comprises the code written in the MATLAB language, which connects the application with MPC backend ('glues' them together). As written in the previous section, communication over HTTP made things simpler, so the glue, once called from the poller, does following steps:

1. Downloads the assignment. By another words, simply instructions about what it shall do. The instructions are transmitted in YAML format of the form, described

in the next section and is interpreted by YAMLMatlab library – details in section 3.6.

2. Looks the assignment for the information about which script to run and launches the script.

The script is specific for every kind of simulation. For currently implemented MPC, the next steps are as follows:

1. Load workspace, needed for the computation. Workspace is stored locally on the worker as a `.mat` file, which is a MATLAB native file format, can hold all its data structures and IO operations with it are fast.

2. Get identifiers of simulation model and controller to know, which part of the data just loaded to use.

3. In the data subtrees, specified by these identifiers, create or rewrite values according to the information in the assignment.

4. If there are overall weights present in the assignment, perform remapping to lo-level weights.

5. According to the assignment, download appropriate time series from the server. These series are downloaded one by one by their dedicated HTTP channel in CSV format, using MATLAB function `urlwrite`, saving it as a temporary file and then the series are loaded into the workspace using `dlmread`.

6. Set initial conditions for the simulation, if provided in the assignment.

7. Call the simulation backend, which formulates the problem using YALMIP and then solves it.

8. Upload resulting time series to the server, using the same principle as their read. Series are sent in CSV format using POST request.

The script occasionally emits log messages about its progress as another special HTTP requests. If there is an exception raised, the script will serialize it as YAML data and sends it to the server as another log message.

3.12.8 Data transfer protocol for an assignment

First data transferred to MATLAB after the task processing is launched is the *assignment*, which is a list of items which are essential for simulation to begin. As said in section 3.12.6, data is transferred using HTTP, which carries YAML text data. Structure, serialized into YAML is a list of dictionaries, each dictionary has following fields:

- `type` – Identifies, which kind of information the item holds.
- `value` – Holds content of the information.

These key set may be extended by some extra fields, when the information the item kind needs it:

- `name` – When the information is targeted to some field in the simulation data structure, the target is specified here.
- `target` – When the target needs to be specified even more and the rest of the information is very similar to another one, this field is the target fine-specifier.

The top-level list items can be of following types:

- `script` – in its `value` defines MATLAB script to be executed for task processing.
- `controller` – in its `value` selects, which simulation controller from the batch of preloaded data will be used.
- `model` – in its `value` selects, which simulation model from the batch of preloaded data will be operated.
- `predictionHorizon` – in its `value` carries length of the prediction horizon (floating point number in the units of hours)
- `outputseries` – in its `value` key stores the primary key of the output data row in the database. The output data will be saved in this row as CSV.
- `initialConditions` – in its `value` has a dictionary, which in its `initial` key holds initial measurement values (to use with Kalman filtration for intial state estimation) and in its `state` key holds directly the initial state vector. Both keys are optional.
- `hiweight` – has 'hi-level weight' in its `value`.
- `refMin/refMax` – Determines the minimum/maximum of a variable in the `value` field. Specifies the targeted entity using the `target` key. This key can route the value to `constraints` or `costFunction`
- `refMinSchedule/refMaxSchedule` – The same as previous point, with the difference in `value` field, which is a dictionary pointing into the data repository and specifying which data cut-out will be downloaded. The dictionary has following keys:
  - `id` – primary key of a data series in the repository
  - `t0` – starting time point of a data series
  - `t1` – end time point of a data series
  - `ts` – sampling period in which the data are expected to be
  - `tsh` – time point to which the first data record will be shifted (and the following ones will be shifted by corresponding value)

  All time entries are in milliseconds.

Chapter 4

Conclusion

The result of the work is a tool, which presents MPC control in a human-accessible interface and distributes time consuming simulations on potentially powerful workers for computation.

During the development, there was an effort not only to accomplish the functionality request but also to create some way engaging environment for the user of the resulting product.

A demonstration of operation – As an example of the application abilities, Figure 4.1 displays how the room temperature tracks the reference as the overall weight setting is changed, by showing the results of simulating one optimization step of MPC, controlling mathematical model of one part of the building (see Section 1.2 for details). The simulation was performed using the Manager interface (described in Section 2.6.8), with settings (comfort:economy) being (1:99), (50:50), (99:1) and variable disturbance (ambient temperature) used, which was fluctuating around $-10°C$.

It can be seen that as the weight trade-off changes from the emphasis on saving money to the emphasis on heat comfort, the resulting room temperature starts to track the reference more and more precisely, which indicates increasing action of the heating system as expected.

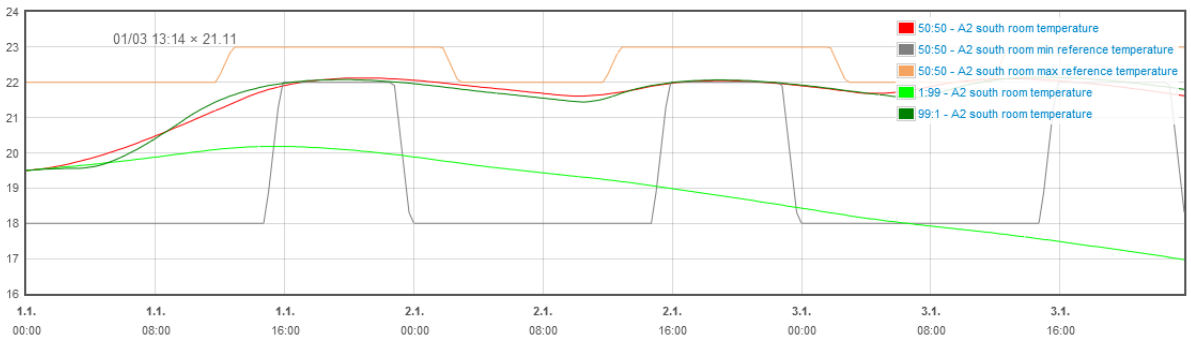


Figure 4.1: Comparison of simulation results, obtained using three different weight settings. In the legend: the ratio expresses the setting 'comfort:economy'. References were the same in all three cases.

On the connection between the web browser and the server – The application uses polling a lot, which is known to be a methodology, wasting a lot of both network and machine resources. The reason it was used is that the application is supposed to be very small-scale (approx. 20 users at once in average plus some workers), so the overhead is acceptable. HTTP protocol is further designed to be a request-response, which suits very well for polling.

It is ineffective to reload part of a page every few seconds, as it is done on several places in the application. The application is finally fairly soft-realtime, which makes the user feeling better, but induces an idea of rewriting at least part of it to use some HTTP push (comet) technology rather than polling. There are several possibilities (Orbited [12], APE [2],...), which can handle the socket abstraction very well. It finally seems like the server is initiating the connection, response in the browser is nearly immediate, resource usage is much more effective.

Push technologies are proven to be fully functional by companies such as Facebook, Meebo and others.

The reason that the push technology was not even tried is that it looked likely to be too heavy-weight for the application and so the author rather concentrated on more important aspect of the application, like its design and philosophy of the framework.

The push technology is finally highly recommended, because at least the knowledge gained during the project would have been excellent, it would establish a base for some future soft-realtime larger-scale projects and finally the tool can not only represent control technology, but a technology as is – in another words, present the knowhow of a control technology plus that we are able to bring it into the life using nice and effective ways.

On the connection between the application and workers – The connection is pretty much of the same kind as the one with the browser. Worker poll the server every five seconds, every poll (the one from the browser as well) often initiates several SQL queries and updates.

The 'passive' task queue would not succeed in any slightly more rush environment simply because SQL servers are not technologically designed to back responsive queues, actually neither the unresponsive ones, but the queue implementation as is definitely suits quite well to the relational storage ('nice theory, ugly practice', to be accurate).

To the future growth of the application, it is highly recommended to use some kind of messaging system. Reasons are roughly the same as these mentioned at the push technology.

Messaging systems are widely used in business applications to communicate between various parts, often to asynchronously distribute time intensive tasks such as document transformations, video processing and so on.

Moreover, there was an idea spoken that the task queue system developed, can be used to distribute the computational power for on-line controlling purposes. This would allow the concept of a few powerful servers, computing the solution and much higher number of some thin clients, used only for communication within these servers and controlled technology.

One problem seen in this approach is that there is no failover safeguard, e.g. what to do if the internet connection is broken. One possible solution is to implement some less

sophisticated control algorithm directly into the thin client, which in case of connection failure would temporarily adopt the control (even with the worse performance), until the connection is fixed. But this is entirely out of the scope of this work.

There are many messaging techniques established. AMQP [1] protocol is one representative, which uses one or more so called message brokers, which are servers, maintaining message queues and connections with communicating clients (message producers and consumers). The system is designed to distribute thousands of messages per second, brokers have often built-in persistence and journaling facilities to overcome restarts and powerdowns, so messages are not lost so easily.

Some messaging systems have also higher level abilities out-of-the-box such as clustering, which increases the messaging system availability.

On the use of Django and its ORM – The author was disappointed many times by the Django framework, as by the reading of many articles about, it had appeared that the framework is really outstanding. But everything has its limits. Django often does more than the developer would like, sometimes contrarywise lacks very basic feature, frequently used elsewhere.

The ORM is subjectively very feature-less, slightly more complex queries are simply impossible to build with it.

But again, Django is the best framework for beginners, has very clear philosophy and absolutely marvellous documentation. Where the documentation eventually says nothing, there tells the source code, which was frequently studied throughout the development.

We should not forget that Django was founded as a rapid development framework for newsrooms, which is quire a specific area. Then, it did its job quite well in the application for control engineering.

As for the next development, it is suggested to rewrite the application to utilize the TurboGears [19] framework. It is much more complex and complicated than Django, but offers the freedom to the developer. It contains SQLAlchemy [18], which is considered to be one of the best ORMs and SQL builders available. It is designed to be open and it is not rare that it offers integration more libraries, doing the same thing (more templating engines, to name one), which allows the developer to make the choice.

To not only prise it, TurboGears has quite ugly documentation, compared to its complexity and not only because of that it has a mild learning curve.

On the development itself – The application took approximately four months of hard work to write to the current appearance. This is can be considered a good job for a person who has never written the web application before.

The total time investment was approximately three times longer though. For the author, it took this long to absorb all technologies and mainly to find the way to the goal, which suits him.

The development was also a very good lesson of self-confidence, which is maybe the most important outcome of this work for the author.

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Content of the attached CD

There is a CD attached to this work, which has following content:

- `BuildingLAB_web` – BuildingLAB (web application)
- `BuildingLAB_worker` – BuildingLAB (worker software)
- `Text` – Electronic version of this text.